The Rise of the Robots

In the U.S.

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About the Editor

Michael Erbschloe has worked for over 30 years performing analysis of the economics of information technology, public policy relating to technology, and utilizing technology in reengineering organization processes. He has authored several books on social and management issues of information technology that were published by McGraw Hill and other major publishers. He has also taught at several universities and developed technology-related curriculum. His career has focused on several interrelated areas:

- Technology strategy, analysis, and forecasting
- Teaching and curriculum development
- Writing books and articles
- Publishing and editing
- Public policy analysis and program evaluation

Books by Michael Erbschloe

Social Media Warfare: Equal Weapons for All (Auerbach Publications)
Walling Out the Insiders: Controlling Access to Improve Organizational Security (Auerbach Publications)
Physical Security for IT (Elsevier Science)
Trojans, Worms, and Spyware (Butterworth-Heinemann)
Implementing Homeland Security in Enterprise IT (Digital Press)
Guide to Disaster Recovery (Course Technology)
Socially Responsible IT Management (Digital Press)
Information Warfare: How to Survive Cyber Attacks (McGraw Hill)
The Executive's Guide to Privacy Management (McGraw Hill)
Net Privacy: A Guide to Developing & Implementing an e-business Privacy Plan (McGraw Hill)

Introduction

In 1982 comments given before a House subcommittee by the General Accountability Office (GAO) presented the view that automation can be an important factor in productivity improvement, although rapid, wide-scale adoption of automation may exacerbate such problems as labor displacement, skill shortages, geographic dislocations, and labor-management bargaining. The U.S. lag in implementing automation in comparison with other industrial nations is in part reflected in the Nation's declining productivity. The barriers to more rapid implementation of automated technologies include: (1) technical barriers which are encountered in getting automated equipment to work; (2) financial barriers which arise from the necessity to invest in new capital equipment such as automated devices; and (3) social barriers which are based on human resistance to change. Published predictions have cited the potential loss of millions of jobs in the manufacturing sector because of the use of robotics. At the same time, new and existing occupations are expected to increase because of the advent and diffusion of automation. Federal efforts to encourage automation include: (1) financial incentives for private sector action; (2) research responsibilities; (3) technology transfer mechanisms; (4) support of engineering education; and (5) the development of standards to facilitate integration of diverse components of automation systems.

(Link: http://www.gao.gov/products/118784)

Welcome to the 21st Century!

One exciting element of the Advanced Manufacturing Partnership is the National Robotics Initiative. Robots are working for us every day, in countless ways. At home, at work, and on the battlefield, robots are increasingly lifting the burdens of tasks that are dull, dirty, or dangerous.

But they could do even more, and that's what the National Robotics Initiative is all about. Four agencies (the National Science Foundation, the National Institutes of Health, NASA, and the United States Department of Agriculture) issued a joint solicitation that will provide up to $70 million in research funding for next-generation robotics.

The focus of this initiative is on developing robots that work with or beside people to extend or augment human capabilities, taking advantage of the different strengths of humans and robots. In addition to investing in the core technology needed for next-generation robotics, the initiative will support applications such as robots that can:

- Increase the productivity of workers in the manufacturing sector;
- Assist astronauts in dangerous and expensive missions;
- Help scientists accelerate the discovery of new, life-saving drugs; and
- Improve food safety by rapidly sensing microbial contamination.

The initiative will also designed to accelerate progress in the field by requiring researchers to share the software and robotics operating systems they develop or contribute to, and funding the purchase of robotics platforms. The Obama Administration decided to make robotics a priority because:

- Robotics can address a broad range of national needs such as advanced manufacturing, logistics, services, transportation, homeland security, defense, medicine, healthcare, space exploration, environmental monitoring, and agriculture;
- Robotics technology is reaching a "tipping point" and is poised for explosive growth because of improvements in core technologies such as microprocessors, sensors, and algorithms;

- Robotics can play an important role in science, technology, engineering and mathematics (STEM) education because it encourages hands-on learning and the integration of science, engineering, and creative thinking; and
- Members of the research community such as the Computing Community Consortium and program managers in key sciences have developed a shared vision and an ambitious technical agenda for developing next-generation robotic systems that can safely work with humans and augment human capabilities.

(Link: https://obamawhitehouse.archives.gov/blog/2011/06/24/developing-next-generation-robots)

The goal of the National Robotics Initiative (NRI) is to support fundamental research that will accelerate the development and use of robots in the United States that work beside or cooperatively with people. The original NRI program focused on innovative robotics research that emphasized the realization of collaborative robots (co-robots) working in symbiotic relationships with human partners.

The 2.0 program significantly extends this theme to focus on issues of scalability: how teams of multiple robots and multiple humans can interact and collaborate effectively; how robots can be designed to facilitate achievement of a variety of tasks in a variety of environments, with minimal modification to the hardware and software; how robots can learn to perform more effectively and efficiently, using large pools of information from the cloud, other robots, and other people; and how the design of the robots' hardware and software can facilitate large-scale, reliable operation.

(Link: https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=503641&org=CISE)

The Need for Industrial Competitiveness

In 1982 comments given before a House subcommittee by the General Accountability Office (GAO) presented the view that automation can be an important factor in productivity improvement, although rapid, wide-scale adoption of automation may exacerbate such problems as labor displacement, skill shortages, geographic dislocations, and labor-management bargaining. While the private sector may assume primary responsibility for developing and implementing automation technology, the Federal Government will probably continue to play some role by developing policies and programs to encourage continued growth in automation and to address related employment problems.

The U.S. lag in implementing automation in comparison with other industrial nations is in part reflected in the Nation's declining productivity. The barriers to more rapid implementation of automated technologies include: (1) technical barriers which are encountered in getting automated equipment to work; (2) financial barriers which arise from the necessity to invest in new capital equipment such as automated devices; and (3) social barriers which are based on human resistance to change. Despite these barriers, current national economic problems stimulate both development and use of automation technology. Published predictions had cited the potential loss of millions of jobs in the manufacturing sector because of the use of robotics. At the same time, new and existing occupations are expected to increase because of the advent and diffusion of automation. Federal efforts to encourage automation include: (1) financial incentives for private sector action; (2) research responsibilities; (3) technology transfer mechanisms; (4) support of engineering education; and (5) the development of standards to facilitate integration of diverse components of automation systems. No current Federal programs are aimed specifically at resolving the problems of unemployment caused by automation, including training in the necessary technical skills. GAO believes that there is a need for an overall plan to guide Federal policies and programs related to automation."

(Link: http://www.gao.gov/products/118784)

In 1992 the GAO reported to Congress that: (1) aggregate performance indicators provide some evidence of a decline in the U.S. leadership position in developing and marketing technology-intensive products, particularly relative to Japan; (2) evidence on trends in the U.S. trade balance in high-technology products is mixed, with measures of high-technology trade sensitive to which products are included; (3) several indicators yield evidence that the technology gap between Japan and the United States has narrowed in recent decades; (4) measures of research output show Japanese gains; (5) the United States is the world leader in the production and consumption of telecommunications equipment; (6) the share of U.S.-owned firms in the domestic and world consumer electronics markets has declined dramatically over the last 40 years; (7) Japan is the world's largest market and producer of semiconductors; and (8) the decline in U.S. position in some industries has been strongest in the less technologically sophisticated industry segments.
(Link: http://www.gao.gov/products/NSIAD-92-236)

In 2013 the GAO reported that over the last decade, the United States lost about one-third of its manufacturing jobs, raising concerns about U.S. manufacturing competitiveness. There may be insights to glean from government policies of similarly-situated countries, which are facing some of the same challenges of increased competition in manufacturing from developing countries.

The four countries GAO analyzed--Canada, Germany, Japan, and South Korea--offer a varied mix of programs to support their manufacturing sectors. For example, Canada is shifting emphasis from its primary research and development (R&D) tax credit toward direct support to manufacturers to encourage innovation, particularly small- and medium-sized enterprises (SMEs). Germany has established applied institutes and clusters of researchers and manufacturers to conduct R&D in priority areas, as well as a national dual training system that combines classroom study with workplace training, and develops national vocational skills standards and credentials in 350 occupations. Japan has implemented science and technology programs--with a major focus on alternative energy projects--as part of a comprehensive manufacturing strategy. South Korea has substantially expanded investments in R&D, including the development of a network of technoparks--regional innovation centers that provide R&D facilities, business incubation, and education and production assistance to industry.

When compared to the United States, the countries in GAO's study offer some key distinctions in government programs to support the manufacturing sector in the areas of innovation, trade, and training.

•While the United States and the other four countries all provide support for innovation and R&D, the foreign programs place greater emphasis on commercialization to help manufacturers bridge the gap between innovative ideas and sales. These include programs that support infrastructure as well as hands-on technical and product development services to firms, and that foster collaboration between manufacturers and researchers. In contrast, the United States relies heavily on competitive funding for R&D projects with commercial potential.

•Within trade policy, the United States and the four countries in GAO's study provide similar services, but there are several differences in how they are delivered. For example, the United States is an acknowledged leader in intellectual property protection, but the U.S. government plays a less prominent role than the Japanese government in developing technological standards on industrial products.

•A key difference related to training programs pertains to the sustained role of government in coordinating stakeholder input into a national system of vocational skills training and credentialing, which helps provide a supply of skilled workers for manufacturers. This was particularly evident in Germany. In contrast, the United States largely devolves vocational training to states and localities and does not have a national system to issue industry-recognized credentials. However, the U.S. manufacturing industry, with participation from the federal government, has recently launched an effort to establish nationally portable, industry-recognized credentials for the manufacturing sector.

(Link: http://www.gao.gov/products/GAO-13-365)

The U.S. manufacturing sector comprises businesses that are engaged in the mechanical, physical, or chemical transformation of materials, substances, or components into new products, including sectors such as machinery, textiles, apparel, food production, and chemicals. However, U.S. policy makers have become focused on competing in high-end, or “advanced manufacturing.” While no consensus definition of advanced manufacturing exists, it refers generally to the production of scientifically- and technologically-intensive products, in which the economic value derives from inputs of knowledge and design more than it reflects traditional inputs such as labor and materials. Robotics, nano-manufacturing, and electric vehicles are examples of advanced

Statistics present a mixed picture about the health of U.S. manufacturing, both relative to the rest of the U.S. economy and to other countries’ manufacturing sectors. According to data from BLS, manufacturing employment has fallen from 17.6 million workers in 1998 to 11.5 million in early 2010, a decline of over one-third over a period in which total U.S. employment grew somewhat. However, the decline in U.S. manufacturing employment is not a new phenomenon, and a longer-term view shows a steady decline of manufacturing’s share of all American jobs.

Since bottoming out in 2010, manufacturing employment rebounded slowly up to about 12 million workers at the end of 2012. Also, other advanced economies, such as Canada, Germany, Japan, and the United Kingdom, suffered large manufacturing job losses from 1998 to 2011, suggesting that global economic forces have affected manufacturing employment in addition to any factors that may be unique to the United States.

Not all experts agree on what role, if any, the government should play in supporting manufacturing. Economic theory generally suggests that government intervention into private sector activity is justified by “market failure”—situations in which the private market under- or over-produces a good because private interests differ from society’s. Those supportive of enhancing productivity in manufacturing suggest that government policy should target the sector in order to remedy market failures that may hinder innovation—the development and application of new knowledge. Innovation underpins improvements in the way capital and labor are combined to create new products and increase productivity. This makes it critical for the broader economy and particularly important for manufacturing.

An important element of innovation is research and development (R&D), the testing and application of new ideas. R&D is seen as a key source of innovation and its application to new products and technologies. The private sector, however, faces disincentives to investing in R&D— it may be expensive, it often fails, willing firms may lack sufficient finances, and successful R&D may produce benefits that the investing firm cannot capture — leading to possible underinvestment in R&D and underproduction in innovation without government support. These disincentives may be particularly difficult to overcome for small- and medium-sized enterprises (SME). Though innovation policy can address market failure across all sectors of the economy, advocates of targeted innovation policy argue that it may provide particular benefit to manufacturing. They note that the sector depends on continually creating new ideas for products and ways to make those products. They also observe that manufacturing is a significant source of R&D; according to the National Science Foundation, the sector accounted for 70 percent of private-sector spending on R&D in the United States in 2008.

In practical terms, to support needed innovation, the government may intervene through various policies, some of which may have a focus on the manufacturing sector. These include:

- Public support for "basic" R&D in science and engineering, which, while conducted without specific commercial applications in mind, can spur private-sector innovation. The public sector may be well-suited to conducting basic R&D directly, through government scientific agencies, public universities, and other research institutions, because it is unlikely that most private firms would conduct this type of general research without a potentially profitable application in mind.
- Public support for private-sector "applied" R&D, research that seeks to solve practical problems or develop new products and commercialization. Applied R&D is seen as a key component in helping innovators overcome the so-called "valley of death", the difficult transition between new ideas and commercially viable manufacturing products or processes. Support for applied R&D could take various forms:

- Subsidies for private investment in R&D, through direct funding or tax incentives, and assistance with financing for private R&D projects with commercialization potential, which may overcome the difficulty some firms may face in obtaining funding from private financial markets. However, it may be difficult for the government to figure out which firms merit subsidy because of the lack of information or foresight into an individual firm's growth prospects.
- Public infrastructure investment that facilitates R&D and knowledge transfer, such as research laboratories, transportation investment, and "knowledge" infrastructure such as broadband telecommunications, the development of measurement techniques and databases, and the dissemination of technical expertise. Experts have referred to such widely-accessible infrastructure or knowledge as the "industrial commons" that provides a base for innovation and production, and see investment in these commons as an important source of new ideas for products or processes and solutions to existing problems.
- Public support for innovation clusters — regional concentrations of large and small companies that develop creative products and services, along with specialized suppliers, service providers, universities, and associated institutions. Firms in a cluster may be able to share knowledge and transact business at lower cost than if they were far apart, possibly leading to increased innovation.8

However, the effectiveness of cluster policy has not been established; the formation of successful clusters in the United States, such as California's Silicon Valley, suggests that government support for clusters may not be necessary. Government support for manufacturing can also involve other efforts that support activities that may suffer from market failures:

- Development of knowledge and workforce skills. Like investment in R&D, private firms may lack the incentive to invest in worker training because the firms may not recoup a sufficient investment if workers take their training to another firm or if skills become obsolete. As manufacturing has become more technologically advanced, various experts have highlighted the increased importance of skills training in advanced manufacturing, as well as the adaptability of workers and training resources. Manufacturing in scientifically-intensive fields will also require a pipeline of workers with advanced degrees in science, technology, engineering, and mathematics. A recent study from the Brookings Institution uses the Bureau of Labor Statistics' data to project that nearly half of all job openings in the U.S. economy over the next decade will be for "middle-skill" jobs, those requiring more than high school but less than a college degree.

- Promotion of open trade and global competition, through trade liberalization, the provision of information, advice, and advocacy for exporters (referred to as export promotion), the protection of intellectual property rights, development and harmonization of international technological standards, and the enforcement of trade rules. While free trade agreements have decreased the significance of tariffs as a trade barrier, some experts have argued that non-tariff barriers have become increasingly problematic. These could include restrictive technical standards, packaging, and local content requirements, among others. Trade policy may be especially critical for manufacturing since the sector may play a key role in restoring a healthy balance of trade. In 2012, Commerce reported that in 2010, manufactured goods represented 86 percent of all U.S. goods exported and 60 percent of total U.S. exports.

In the United States, the federal government has generally taken the lead in supporting basic research, providing the economic framework, and constructing infrastructure. Commerce administers manufacturing programs through sub-agencies such as the National Institute of Standards and Technology (NIST), the Economic Development Administration (EDA), and the International Trade Administration. Other U.S. agencies support manufacturing as part of their program activities, including the Department of Defense, the Department of Energy, National Aeronautics and Space Administration, and the National Science Foundation. Labor administers training programs for job seekers through the Employment and Training Administration. In addition, tax breaks such as the R&D tax credit further benefit manufacturers (although these provisions do not apply exclusively to manufacturers). States and localities have the main responsibility for education and also are most active in promoting regional economic development, including measures that support innovation.

The United States has developed as a global leader, in large part, through the genius and hard work of its scientists, engineers, and innovators. In a world that's becoming increasingly complex, where success is driven not only by what you know, but by what you can do with what you know, it's more important than ever for our youth to be equipped with the knowledge and skills to solve tough problems, gather and evaluate evidence, and make sense of information. These are the types of skills that students learn by studying science, technology, engineering, and math—subjects collectively known as STEM.

Yet today, few American students pursue expertise in STEM fields—and we have an inadequate pipeline of teachers skilled in those subjects. That's why it is a high priority to increase the number of students and teachers who are proficient in these vital fields.

All young people should be prepared to think deeply and to think well so that they have the chance to become the innovators, educators, researchers, and leaders who can solve the most pressing challenges facing our nation and our world, both today and tomorrow. But, right now, not enough of our youth have access to quality STEM learning opportunities and too few students see these disciplines as springboards for their careers.
(Link: https://www.ed.gov/stem)

The STEM Plan in Brief

The Committee on STEM Education (CoSTEM), comprised of 13 agencies—including all of the mission-science agencies and the Department of Education—are facilitating a cohesive national strategy, with new and repurposed funds, to increase the impact of federal investments in five areas: 1.) improving STEM instruction in preschool through 12th grade; 2.) increasing and sustaining public and youth engagement with STEM; 3.) improving the STEM experience for undergraduate students; 4.) better serving groups historically underrepresented in STEM fields; and 5.) designing graduate education for tomorrow's STEM workforce

Coordinated efforts to improve STEM education are outlined in the federal, 5-year Strategic Plan for STEM Education and concentrate on improving the delivery, impact, and visibility of STEM efforts. Additionally, the Department of Education, the National Science Foundation, and the Smithsonian Institution are leading efforts to improve outcomes for traditionally underrepresented groups.

The health and longevity of our Nation's, citizenry, economy and environmental resources depend in large part on the acceleration of scientific and technological innovations, such as those that improve health care, inspire new industries, protect the environment, and safeguard us from harm. Maintaining America's historical preeminence in the STEM fields will require a concerted and inclusive effort to ensure that the STEM workforce is equipped with the skills and training needed to excel in these fields. During President Obama's first term, the Administration used multiple strategies to make progress on improving STEM education:

- Making STEM a priority in more of the Administration's education efforts. The first round of the Department of Education's $4.3 billion Race to the Top competition offered states a competitive preference priority on developing comprehensive strategies to improve achievement and provide rigorous curricula in STEM subjects; partner with local STEM institutions, businesses, and museums; and broaden participation of women and girls and other groups underrepresented in STEM fields. Other examples include STEM priorities in the Department of Education's Invest in Innovation and Supporting Effective Educator Development programs. Prioritizing STEM in existing programs at the Department of Education has the advantage of leveraging existing resources and embedding STEM within our overall education reform efforts.

- Setting ambitious but achievable goals and challenging the private sector. President Obama announced the goal to prepare 100,000 excellent STEM teachers over the next decade in his 2011 State of the Union Address. Answering this call to action, over 150 organizations led by the Carnegie Corporation of New York formed a coalition called 100Kin10. Members of the coalition have made over 150 commitments to support STEM-teacher preparation and had raised over $30 million for this effort. In mid-March, the Howard Hughes Medical Institute announced a $22.5M investment to support expansion of the successful UTeach program in support of this goal. Additional examples of this all-hands-on-deck approach to challenging companies, foundations, non-profits, universities, and skilled volunteers include Change the Equation, US2020, and the scaling up and expanding an AP program for children in military families.

- The first-ever White House Science Fair took place in late 2010 and the second in 2012, fulfilling a commitment made at the launch of the Educate to Innovate campaign to directly use the pulpit to inspire more boys and girls to excel in mathematics and science. A call to action was issued to the 200,000 Federal scientists and engineers to volunteer in their local communities and think of creative ways to engage students in STEM subjects. Improving STEM education will continue to be a high priority in President Obama's second term. Guided by the aims articulated in the February 2012 Progress Report and subsequent pre-final drafts of this Strategic Plan—as well by the President's desire to re-organize STEM-education programs for greater coherence, efficiency, ease of evaluation, and focus on his highest priorities—the Executive Office of the President recommended, and the President accepted, a FY2014 Budget Request for STEM education that would increase the total investment in STEM-ed programs by 6 percent over the 2012 appropriated level.

- The Department of Education was designated to play an increased role in improving P-12 STEM instruction by supporting partnerships among school districts and universities, science agencies, businesses, and other community partners to transform teaching and learning. It also invested an additional $80 million in support of the 100,000 new STEM-ed teachers goal and $35 million for the launch of a pilot STEM-ed Master Teacher Corps, as well as in creation of new STEM Innovation Networks to better connect school districts with local, regional, and national STEM resources. The Department also collaborated with all of the CoSTEM agencies to ensure that Federal scientific assets were utilized in the improvement of P-12 STEM education.

- The National Science Foundation increased its focus on improving the delivery of undergraduate STEM teaching and learning through evidence-based reforms, including a new $123 million program aimed at improving retention of undergraduates in STEM fields. NSF also received $325 million to expand and enhance its graduate fellowship programs, including creation of a new National Graduate Research Fellowship, using a common infrastructure at NSF to reach more students and offer a set of opportunities that address national needs and mission critical workforce needs for the CoSTEM agencies.

- The Smithsonian Institution received $25 million to focus on improving the reach of informal STEM education by ensuring that materials are aligned to what students are learning in the classroom. The Smithsonian worked with NSF, ED, the other CoSTEM agencies including the National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), U.S. Department of the Interior (DOI), U.S. Department of Agriculture (USDA), National Institutes of Health (NIH), and other science partners to harness their unique expertise and resources to disseminate relevant, evidence-based materials and curricula, on-line resources, and delivery and dissemination mechanisms to reach more teachers and students both inside and outside the classroom.

All of the CoSTEM agencies continued to be key players in the re-organized effort. All of these agencies depend upon the cultivation of a talented and well-trained workforce in order to meet their STEM-related missions, and all of them play a critical role in inspiring and training the next generation of STEM workers. Whether it be through direct support, provision of expertise and content, mobilization of talented STEM role models and mentors, or by exposing students to real-world learning opportunities at Federal STEM facilities, these agencies inspire and inform future scientists, engineers, innovators, and explorers.

The Strategic Plan complements the important steps already taken. The Plan begins by providing an overview of the importance of STEM education to American scientific discovery and innovation, the need to better prepare students for today's jobs and those of the future, and the importance of a STEM-literate society and also describes the current state of Federal STEM education efforts. The document then presents five priority STEM education investment areas where a coordinated Federal strategy can be developed, over five years, designed to lead to major improvements in key areas. This increased coordination is expected to bring significant gains in efficiency and coverage.

Also included in this plan are initial implementation roadmaps in each of the priority STEM education investment areas, proposing potential short-, medium-, and long-term objectives and strategies that might help Federal agencies achieve the outlined goals. Additionally, throughout the document, the plan highlights (1) key outcomes for the Nation and ways Federal agencies can contribute, (2) areas where agencies will play lead roles, thereby increasing accountability, (3) methods to build and share evidence, and (4) approaches for decreasing fragmentation. The Strategic Plan will allow the U.S. to better achieve a number of inter-related goals:

- It will help Federal STEM efforts reach more students and more teachers more effectively by reorienting Federal policy to meet the needs of those who are delivering STEM education: school districts, States, and colleges, and universities;

- It will help in reorganizing efforts and redirecting resources around more clearly defined priorities, with accountable lead agencies;

- It will enable rigorous evaluation and evidence-building strategies for Federal STEM-education programs;

- It will increase the impact of Federal investments in important areas such as graduate education by expanding resources for a more limited number of programs, while recognizing shortages in key disciplines and professions; and,

- It will provide additional resources to meet specific national goals, such as preparing and recruiting 100,000 high-quality K-12 STEM teachers, recognizing and rewarding excellence in STEM instruction, strengthening the infrastructure for supporting STEM instruction and engagement, increasing the number of undergraduates with a STEM degree by one million over the next decade, and broadening participation in STEM fields by underrepresented groups.

The STEM Strategic Plan sets out ambitious national goals to drive Federal investment in five12 priority STEM education investment areas:

- Improve STEM Instruction: Prepare 100,000 excellent new K-12 STEM teachers by 2020, and support the existing STEM teacher workforce;
- Increase and Sustain Youth and Public Engagement in STEM: Support a 50 percent increase in the number of U.S. youth who have an authentic STEM experience each year prior to completing high school;
- Enhance STEM Experience of Undergraduate Students: Graduate one million additional students with degrees in STEM fields over the next 10 years;
- Better Serve Groups Historically Under-represented in STEM Fields: Increase the number of students from groups that have been underrepresented in STEM fields that graduate with STEM degrees in the next 10 years and improve women's participation in areas of STEM where they are significantly underrepresented; and,
- Design Graduate Education for Tomorrow's STEM Workforce: Provide graduate-trained STEM professionals with basic and applied research expertise, options to acquire specialized skills in areas of national importance, mission-critical workforce needs for the CoSTEM agencies, and ancillary skills needed for success in a broad range of careers. (Link: https://www.whitehouse.gov/sites/default/files/microsites/ostp/stem_stratplan_2013.pdf)

The National Robotics Initiative (NRI)

The goal of the National Robotics Initiative (NRI) is to support fundamental research that will accelerate the development and use of robots in the United States that work beside or cooperatively with people. The original NRI program focused on innovative robotics research that emphasized the realization of collaborative robots (co-robots) working in symbiotic relationships with human partners.

The 2.0 program significantly extends this theme to focus on issues of scalability: how teams of multiple robots and multiple humans can interact and collaborate effectively; how robots can be designed to facilitate achievement of a variety of tasks in a variety of environments, with minimal modification to the hardware and software; how robots can learn to perform more effectively and efficiently, using large pools of information from the cloud, other robots, and other people; and how the design of the robots' hardware and software can facilitate large-scale, reliable operation.

In addition, the program supports innovative approaches to establish and infuse robotics into educational curricula, advance the robotics workforce through education pathways, and explore the social, behavioral, and economic implications of our future with ubiquitous collaborative robots. Collaboration between academic, industry, non-profit, and other organizations is encouraged to establish better linkages between fundamental science and engineering and technology development, deployment and use. Well-justified international collaborations that add significant value to the proposed research and education activities will also be considered.

The 2.0 program is supported by multiple agencies of the federal government including the National Science Foundation (NSF), the U.S. Department of Agriculture (USDA), the U.S. Department of Energy (DOE), and the U.S. Department of Defense (DOD).

(Link: https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=503641&org=CISE)

National Science Foundation Grant Awards

About the National Science Foundation (NSF): The NSF is an independent federal agency that supports fundamental research and education across all fields of science and engineering. In fiscal year (FY) 2012, its budget was $7.0 billion. NSF funds reach all 50 states through grants to nearly 2,000 colleges, universities and other institutions. Each year, NSF receives about 50,000 competitive requests for funding, and makes about 11,500 new funding awards. NSF also awards about $593 million in professional and service contracts yearly. http://www.nsf.gov

The National Science Foundation has granted over 200 awards for robotics research including:

- 2015 International Workshop on Robotics and Interactive Technologies For Neuroscience and Rehabilitation
- A Cognitive Navigation Assistant for the Blind
- A Compliant Lower-Body Exoskeleton to Enable Balanced Walking for Patients with Spinal Cord Injuries
- A Design Methodology for Multi-fingered Robotic Hands with Second-order Kinematic Constraints
- A Dynamic Bayesian Approach to Real Time Estimation and Filtering in Grasp Acquisition and Other Contact Tasks (Continuation)
- A Framework for Hierarchical, Probabilistic Planning and Learning
- A Model based Approach to Distributed Adaptive Sampling of Spatio-Temporally Varying Fields
- A Proactive Approach to Managing Contingencies during Human Robot Collaboration in Manufacturing
- A Variable Stiffness Artificial Muscle Material for Dexterous Manipulation
- Achieving Selective Kinematics and Stiffness in Flexible Robotics
- Active Sensing for Robotic Cameramen
- Active Tendon-Driven Orthosis for Prehensile Manipulation After Stroke
- Adaptive Motion Planning and Decision-Making for Human-Robot Collaboration in Manufacturing
- Additive Manufacturing of Soft Robot Components with Embedded Actuation and Sensing
- Autonomous Quadrotors for 3D Modeling and Inspection of Outdoor Infrastructure
- Characterizing Physical Interaction in Instrument Manipulations
- Co-Exploration using Science Hypothesis Maps
- Collaborative Planning for Human-robot Science Teams
- Complementary Situational Awareness for Human-Robot Partnerships
- Compliant Multifunctional Robotic Structures for Safety and Communication by Touch
- Contextually Grounded Collaborative Discourse for Mediating Shared Basis in Situated Human Robot Dialogue
- Coordinated Detection and Tracking of Hazardous Agents with Aerial and Aquatic Robots to Inform Emergency Responders
- Design and Fabrication of Robot Hands for Dexterous Tasks
- Design of nanorobotics based on iron-palladium alloy nanohelicses for a new diagnosis and treatment of cancer
- Designing semi-autonomous networks of miniature robots for inspection of bridges and other large infrastructures

- Development of an Instrument that Monitors Behaviors Associated with Obsessive-Compulsive Behaviors and Schizophrenia
- Development of Autonomous Sub-Gram Flapping-Wing Artificial Flyers Using Novel Combustion-Driven SMA-Based Actuators
- Dexterous Manipulation with Underactuated Hands: Strategies, Control Primitives, and Design for Open-Source Hardware
- Don't Read my Face: Tackling the Challenges of Facial Masking in Parkinson's Disease Rehabilitation through Co-Robot Mediators
- Dynamic Braces for Quantification and Treatment of Abnormal Curves in the Human Spine
- Dynamic Locomotion: From Humans to Robots via Optimal Control
- Dynamic Robot Guides for Emergency Evacuations
- EEG and EMG Human Model-Based Adaptive Control of a Dexterous Artificial Hand
- Efficient Algorithms for Contact-Aware State Estimation
- Enabling Research in Natural Communication with Virtual Tutors, Therapists, and Robotic Companions
- Enabling Risk-Aware Decision Making in Human-Guided Unmanned Surface Vehicle Teams
- Enabling Unmanned Aerial Systems (UAS) Fire Ignitions in Complex Firefighting Contexts
- Experiential Learning for Robots: From Physics to Actions to Tasks
- Expert-Apprentice Collaboration
- Exploiting Granular Mechanics to Enable Robotic Locomotion
- Fast and Accurate Infrastructure Modeling and Inspection with Low-Flying Robots
- Flexible Multi-Leg Robots for Safe Interaction and Surgical Dexterity
- Formal Methods for Motion Planning and Control with Human-in-the-Loop
- Functional Imitation of Observed Tasks by Co-Robots
- Goal-Oriented, subject-Adaptive, robot-assisted Locomotor Learning (GOALL)
- Human Cognition Assisted Control of Industrial Robots for Manufacturing
- Human-Centered Modeling and Control of Cooperative Manipulation with Bimanual Robots
- Human-robot Coordinated Manipulation and Transportation of Large Objects
- Human-Supervised Perception and Grasping in Clutter
- Improved safety and reliability of robotic systems by faults/anomalies detection from uninterpreted signals of computation graphs
- Improving the Safety and Agility of Robotic Flight with Bat-Inspired Flexible-Winged Robots
- Inferring Mechanical Explanations from Manipulation Demonstrations
- Integrated modeling and manufacturing framework for soft fluidic robotics
- Jointly Learning Language and Affordances
- Large-Scale Collaborative Semantic Mapping using 3D Structure from Motion
- Learning Adaptive Representations for Robust Mobile Robot Navigation from Multi-Modal Interactions
- Learning Deep Sensorimotor Policies for Shared Autonomy

- Learning from Demonstration for Cloud Robotics
- Learning to Plan for New Robot Manipulation Tasks
- Legged Locomotion for Desert Research
- Liquid Handling Robots - A New Paradigm for STEM Education
- Maneuverable Feedback-Controlled Micro Swimming Drone for Biomedical Applications
- Medium: Experience-Based Planning: A Framework for Lifelong Planning
- Minimally Invasive Robotic Non-Destructive Evaluation and Rehabilitation for Bridge Decks (Bridge-MINDER)
- Modeling and Verification of Language-based Interaction
- Modeling, Quantification, and Optimization of Prosthesis-User Interface
- Models and Instruments for Integrating Effective Human-Robot Teams into Manufacturing
- Multi-Digit Coordination by Compliant Connections in an Anthropomorphic Hand
- Multilateral Manipulation by Human-Robot Collaborative Systems
- Multi-modal sensor skin and garments for healthcare and home robots
- Novel microLIDAR Design and Sensing Algorithms for Flapping-Wing Micro-Aerial Vehicles
- NSF National Robotics Initiative (NRI) 2016 PI Meeting
- Operating in the Abyss: Bringing Together Humans and Bio-Inpsired Autonomous Vehicles for Maritime Applications
- Optimal Interaction Design Framework for Powered Lower-Extremity Exoskeletons
- Peer-to-Peer Human-Robot Coalitions
- Planning, Collaborative Guidance and Navigation in Uncertain Dynamic Environments
- Purposeful Prediction: Co-robot Interaction via Understanding Intent and Goals
- Rapid exploration of robotic ankle exoskeleton control strategies
- Real Time Observation, Inference and Intervention of Co-Robot Systems Towards Individually Customized Performance Feedback Based on Students' Affective States
- Real-Time Semantic Computer Vision for Co-Robotics
- Receding Horizon Integrity-A New Navigation Safety Methodology for Co-Robotic Passenger Vehicles
- Reflection and Diffraction Sound Signals for Non-Field-of-View Target Estimation
- Reflex approximation of optimal control for an energy-efficient bipedal walking platform
- Rehabilitation through Co-Robot Mediators
- Representing and Anticipating Actions in Human-Robot Collaborative Assembly Tasks
- Rich Task Perception for Programming by Demonstration
- Robot Developmental Learning of Skilled Actions
- Robotic Tool-Use for Cleaning
- Robotic Treadmill Therapy for Lower Spinal Cord Injuries
- RobotSLANG: Simultaneous Localization, Mapping, and Language Acquisition
- Robust and Low-Cost Smart Skin with Active Sensing Network for Enhancing Human-Robot Interaction
- Shall I Touch This?: Navigating the Look and Feel of Complex Surfaces

- Shape Morphing Arm Robotic (SMART) Manipulators for Simultaneous Safe Human-Robot Interaction and High Performance in Manufacturing
- Simulation Guided Design To Optimize the Performance of Robotic Lower Limb Prostheses
- Sketching Geometry and Physics Informed Inference for Mobile Robot Manipulation in Cluttered Scenes
- Soft Compliant Robotic Augmentation for Human-Robot Teams
- Software Framework for Research in Semi-Autonomous Teleoperation
- Targeted Observation of Severe Local Storms Using Aerial Robots
- Task Dependent Semantic Modeling for Robot Perception
- Task-Based Assistance for Software-Enabled Biomedical Devices
- The Intelligent Workcell - Enabling Robots and People to Work Together Safely in Manufacturing Environments
- Towards Restoring Natural Sensation of Hand Amputees via Wearable Surface Grid Electrodes
- Towards Robots with Human Dexterity
- Understanding neuromuscular adaptations in human-robot physical interaction for adaptive robot co-workers
- Using Multi-Robot Enabled Dexterous Locomotion to Search for Victims in Disaster Areas
- Versatile Locomotion: From Walking to Dexterous Climbing With a Human-Scale Robot
- Vine Robots: Achieving Locomotion and Construction by Growth
- Virtualized Robot Test and Integration Laboratory
- Virtualized Welding: A New Paradigm for Intelligent Welding Robots in Unstructured Environment

NIH Funds Development of Novel Robots to Assist People with Disabilities, Aid Doctors

The National Institutes of Health (NIH) participated in the NRI with the National Science Foundation, the National Aeronautics and Space Administration, and the U.S. Department of Agriculture. NIH has funded three projects to help develop co-robots that can assist researchers, patients, and clinicians.

NIH is the nation's medical research agency, includes 27 Institutes and Centers and is a component of the U.S. Department of Health and Human Services. NIH is the primary federal agency conducting and supporting basic, clinical, and translational medical research, and is investigating the causes, treatments, and cures for both common and rare diseases. For more information about NIH and its programs, visit http://www.nih.gov.

The National Institute of Biomedical Imaging and Bioengineering (NIBIB) mission is to support multidisciplinary research and research training at the crossroads of engineering and the biological and physical sciences. NIBIB supports emerging technology research and development within its internal laboratories and through grants, collaborations, and training. More information is available at the NIBIB website: http://www.nibib.nih.gov.

The National Eye Institute (NEI) leads the federal government's research on the visual system and eye diseases. NEI supports basic and clinical science programs that result in the development of sight-saving treatments. For more information, visit http://www.nei.nih.gov

The National Institute of Nursing Research (NINR) supports basic and clinical research that develops the knowledge to build the scientific foundation for clinical practice, prevent disease and disability, manage and eliminate symptoms caused by illness, and enhance end-of-life and palliative care. For more information about NINR, visit the website at http://www.ninr.nih.gov

Three projects have been awarded funding by the National Institutes of Health to develop innovative robots that work cooperatively with people and adapt to changing environments to improve human capabilities and enhance medical procedures. Funding for these projects totals approximately $2.4 million over next five years, subject to the availability of funds.

A Co-Robotic Navigation Aid for the Visually Impaired: The goal is to develop a co-robotic cane for the visually impaired that has enhanced navigation capabilities and that can relay critical information about the environment to its user. Using computer vision, the proposed cane will be able to recognize indoor structures such as stairways and doors, as well as detect potential obstacles. Using an intuitive human-device interaction mechanism, the cane will then convey the appropriate travel direction to the user. In addition to increasing mobility for the visually impaired and thus quality of life, methods developed in the creation of this technology could lead to general improvements in the autonomy of small robots and portable robotics that have many applications in military surveillance, law enforcement, and search and rescue efforts. Cang Ye, Ph.D., University of Arkansas at Little Rock (co-funded by the National Institute of Biomedical Imaging and Bioengineering and the National Eye Institute)

MRI-Guided Co-Robotic Active Catheter: Atrial fibrillation is an irregular heartbeat that can increase the risk of stroke and heart disease. By purposefully ablating (destroying) specific areas of the heart in a controlled fashion, the propagation of irregular heart activity can be prevented. This is generally achieved by threading a catheter with an electrode at its tip through a vein in the groin until it reaches the patient's heart. However, the constant movement of the heart as well as unpredictable changes in blood flow can make it difficult to maintain consistent contact with the heart during the ablation procedure, occasionally resulting in too large or too small of a lesion. The aim is to develop a co-robotic catheter that uses novel robotic planning strategies to compensate for physiological movements of the heart and blood and that can be used while a patient undergoes MRI—an imaging method used to take pictures of soft tissues in the body such as the heart. By combining state-of-the art robotics with high-resolution, real-time imaging, the co-robotic catheter could significantly increase the accuracy and repeatability of atrial fibrillation ablation procedures. M. Cenk Cavusoglu, Ph.D., Case Western Reserve University, Cleveland (funded by the National Institute of Biomedical Imaging and Bioengineering)

Novel Platform for Rapid Exploration of Robotic Ankle Exoskeleton Control: Wearable robots, such as powered braces for the lower extremities, can improve mobility for individuals with impaired strength and coordination due to aging, spinal cord injury, cerebral palsy, or stroke. However, methods for determining the optimal design of an assistive device for use within a specific patient population are lacking. This project proposes to create an experimental platform for an assistive ankle robot to be used in patients recovering from stroke. The platform will allow investigators to systematically test various robotic control methods and to compare them based on measurable physiological outcomes. Results from these tests will provide evidence for making more effective, less expensive, and more manageable assistive technologies. Gregory S. Sawicki, Ph.D., North Carolina State University, Raleigh; Steven Collins, Ph.D., Carnegie Mellon University, Pittsburgh (co-funded by the National Institute of Nursing Research and the National Science Foundation)

USDA Awards $3 Million for Robotics Research through Joint Agency Initiative

The U.S. Department of Agriculture's (USDA) National Institute of Food and Agriculture (NIFA) announced $3 million in grants to advance the use of co-robots that benefit and assist stakeholders in America's production agriculture field. These three grants are part of the National Robotics Initiative (NRI), a federal research partnership that includes NIFA, the National Science Foundation (NSF), National Institutes of Health (NIH), National Aeronautics and Space Administration (NASA), Department of Defense, and Department of Energy.

The goal of the National Robotics Initiative is to accelerate the development and use of robots in the U.S. that work alongside or cooperatively with people. This program aims to develop the next generation of robotics, advance the capability and usability of such systems and artifacts, and to encourage existing and new communities to focus on innovative application areas. Since 2009, USDA has invested $19 billion in research, both intramural and extramural. During that time, research conducted by USDA scientists has resulted in 883 patent applications filed, 405 patents issued and 1,151 new inventions disclosures covering a wide range of topics and discoveries.

NIFA's role in the NRI focuses on research that enhances food production, processing, and distribution that benefit consumers and rural communities. Examples of technologies to be investigated include:

•Automated systems for inspection, sorting, processing, or handling of animal or plant products (including forest products) in post-harvest, processing or product distribution environments.

•Improved robotics for inspection, sorting, and handling of plants and flowers in greenhouses and nurseries or for handling (e.g., sorting, vaccinating, deworming) large numbers of live animals.

•Multi-modal and rapid sensing systems for detecting microbial contamination, defects, ripeness, physical damage, size, shape, and other quality attributes of plant or animal products (including forest products) or for monitoring air or water quality.

Additionally, projects are expected to engage with industry and academia to identify research needs and provide training for the next generation of scientists, engineers, and technologists.

NIFA invests in and advances agricultural research, education, and extension and seeks to make transformative discoveries that solve societal challenges. To learn more about NIFA's impact on agricultural science, visit nifa.usda.gov/impacts. Grants awarded in fiscal year 2015 were:

- University of California, Davis, Calif., $1,069,598 – The goal of this project is to develop theoretical and technological tools that will enable the design, optimization, prototyping and field-testing of consistently high-throughput, cost-effective mechanized harvesting systems for modern orchards.
- University of Minnesota, St. Paul, Minn., $914,565 – This project aims to develop planning algorithms for robots to autonomously operate in complex environments such as apple orchards so that Commercial Off-The-Shelf (COTS) robot systems can be used in automation tasks involving specialty crops.
- University of Pennsylvania, Philadelphia, Pa., $556,726 – This project utilizes swarms of Unmanned Aerial Vehicles (UAVs) that operate with human scouts to research solutions for specialty crop farmers, improving how farmers can obtain timely estimates of yields, diagnose crop stress, and detect pests.

Since 2009, USDA has invested $19 billion in research, both intramural and extramural. During that time, research conducted by USDA scientists has resulted in 883 patent applications filed, 405 patents issued and 1,151 new inventions disclosures covering a wide range of topics and discoveries.

(Link: https://nifa.usda.gov/announcement/usda-awards-3-million-robotics-research-through-joint-agency-initiative)

The Agriculture and Food Research Initiative (AFRI) is the nation's leading competitive grants program for agricultural sciences. The National Institute of Food and Agriculture (NIFA) awards AFRI research, education, and extension grants to combat childhood obesity, improve rural economies, increase food production, create new sources of energy, mitigate the impacts of climate variability, address water availability issues, ensure food safety and security, and train the next generation of agricultural workforce.

AFRI was established by Congress in the 2008 Farm Bill and re-authorized in the 2014 Farm Bill. The President's FY 2017 budget request proposed to fully fund AFRI for $700 million. This amount is the full funding level authorized by Congress when it established AFRI in the 2008 Farm Bill and would double the $350 million made available in FY 2016. As part of the President's FY 2017 Budget proposal, AFRI investments will target the diverse challenges facing agricultural producers—from climate change to pollinator health to antimicrobial resistant bacteria. In addition to the $375 million provided in the discretionary request, the budget includes a legislative action to make available $325 million in mandatory funding for the program as part of a government-wide investment in research and development.

NIFA provides AFRI grants to support research, education and extension activities in six Farm Bill priority areas: plant health and production and plant products; animal health and production and animal products; food safety, nutrition, and health; bioenergy, natural resources, and environment; agriculture systems and technology; and agriculture economies and rural communities. AFRI-funded science is vital to meeting food, fiber, and fuel demands as the world's population races toward a projected 9 billion by 2050 concomitant with diminishing land and water resources and increasingly variable climatic conditions. In addition, AFRI programs help develop new technologies and a workforce that will advance our national security, our energy self-sufficiency, and the health of Americans.

NIFA's AFRI funding portfolio includes both single- and multi-function research, education, and extension grants that address key problems of national, regional, and multi-state importance. AFRI-funded projects sustain all components of agriculture, including farm efficiency and profitability, ranching, renewable energy, forestry (both urban and agroforestry), aquaculture, rural communities and entrepreneurship, human nutrition, food safety, biotechnology, and conventional breeding. These projects also create jobs and help develop the next generation of agriculture and food scientists.

AFRI-funded integrated projects must include at least two of the three functions of agriculture knowledge – research, education, and extension – to ensure delivery of science-based knowledge to people, allowing them to make informed practical decisions.

The AFRI portfolio includes Coordinated Agricultural Projects (CAP) and Food and Agricultural Science Enhancement (FASE) grants. CAP grants are large, multi-million dollar projects that involve multiple institutions. FASE grants help institutions become more competitive and attract new scientists and educators to careers in high-priority areas of agriculture.

NIFA makes grants for high priority research, education, and extension, taking into consideration the determinations made by the National Agricultural Research, Extension, Education, and Economics Advisory Board.

Subject to the availability of appropriations to carry out the AFRI program, the Secretary may award grants to state agricultural experiment stations; colleges and universities; university research foundations; other research institutions and organizations; federal agencies; national laboratories; private organizations or corporations; individuals; or any group consisting of two or more of the aforementioned entities.

(Link: https://nifa.usda.gov/program/agriculture-and-food-research-initiative-afri)

NASA Selects Advanced Robotics Projects for Development

NASA has a long history of developing cutting-edge robotic systems for use in space exploration. NASA also partners with American businesses, universities and other federal agencies to transfer those technologies back into the nation's industrial base, improving manufacturing capabilities and economic competitiveness.

Recently, tremendous advances in robotics technology have enabled a new generation of assistive systems and devices in industries as diverse as manufacturing, logistics, medicine, health care, military, agriculture, and consumer products.

As part of the National Robotics Initiative, NSF, NASA, the National Institutes of Health and the U.S. Department of Agriculture have managed a joint solicitation, seeking to engage our next generation of roboticists for the new global technology economy. All participating federal agencies are working with partners to foster the exchange of ideas and technologies that will directly benefit American today and well into the future.

NASA has selected eight advanced robotics projects that will enable the agency's future missions while supporting the Obama administration's National Robotics Initiative. The projects, ranging from technologies for improving robotic planetary rovers to humanoid robotic systems, will support the development and use of robots for space exploration, as well as by manufacturers and businesses in the United States.

Robots can work beside, or cooperatively, with people to enhance individual human capabilities, performance and safety in space as well as here on Earth. Co-robotics, where robots work cooperatively with people to enhance their individual human capabilities, performance and safety is a valuable tool for maintaining American leadership in aerospace technology and advanced manufacturing.

The proposals NASA has selected for development are:

1. "Toward Human Avatar Robots for Co-Exploration of Hazardous Environments," J. Pratt, principal investigator, Florida Institute of Human Machine Cognition, Pensacola
2. "A Novel Powered Leg Prosthesis Simulator for Sensing and Control Development," H. Herr, principal investigator, Massachusetts Institute of Technology, Cambridge
3. "Long-range Prediction of Non-Geometric Terrain Hazards for Reliable Planetary Rover Traverse," R. Whittaker, principal investigator, Carnegie Mellon University, Pittsburgh
4. "Active Skins for Simplified Tactile Feedback in Robotics," S. Bergbreiter, principal investigator, University of Maryland, College Park

5. "Actuators for Safe, Strong and Efficient Humanoid Robots," S. Pekarek, principal investigator, Purdue University
6. "Whole-body Telemanipulation of the Dreamer Humanoid Robot on Rough Terrains Using Hand Exoskeleton (EXODREAM)," L. Sentis, principal investigator, University of Texas at Austin
7. "Long, Thin Continuum Robots for Space Applications," I. Walker, principal investigator, Clemson University, Clemson, S.C.
8. "Manipulating Flexible Materials Using Sparse Coding," R. Platt, principal investigator, State University of New York, Buffalo

The National Science Foundation (NSF) managed the solicitation and peer review selection process for these NASA awards. Awards range from $150,000 to $1 million, with a total NASA investment of $2.7 million.

(Link: https://www.nasa.gov/home/hqnews/2012/sep/HQ_12-323_NASA_NRI_Advanced_Robotics.html)

NASA's Office of the Chief Technologist (OCT) has commissioned a series of technology roadmaps that identify both component level needs and larger challenges and missions for the next 20 years. Of the 14 roadmaps, Technology Area 4 is titled "Robotics, Tele-Robotics and Autonomous Systems". Several challenges are identified that are well aligned with the co-robotics theme for developing machines to help humans explore space:

◦Object recognition and pose estimation

◦Fusing visual, tactile and force sensors for manipulation

◦Achieving human-like performance for piloting vehicles

◦Access to extreme terrain in zero, micro and reduced gravity

◦Grappling and anchoring to asteroids and non-cooperating objects

◦Exceeding human-like dexterous manipulation

◦Full immersion telepresence with haptic, multi sensor feedback

◦Understanding and expressing intent between humans and robots

◦Verification of autonomous systems

◦Supervised autonomy of dynamic/contact tasks across time delay

◦Mobile manipulation that is safe for working with and near humans

◦Autonomous rendezvous, prox ops and docking in extreme conditions

(Link: https://www.nasa.gov/robotics/index.html)

NASA Holds Final Sample Return Robot Competition

After five years of competition by more than 40 different teams from around the globe, NASA's Sample Return Robot Challenge has reached its final stage. The top seven teams competed for the $1.36 million prize purse on the campus of Worcester Polytechnic Institute (WPI) in Worcester, Massachusetts, September 4-6, 2016.

In this final round of the challenge, teams have up to two hours each to locate as many as 10 unknown samples that vary in size, shape, location and difficulty. The samples are classified as easy, intermediate and hard and are assigned corresponding point values. One team could win the entire prize purse, or multiple teams could share a percentage of the prize. Qualifying teams for the final round were:

•Team Al - Toronto, Canada

•Alabama Astrobotics - Tuscaloosa, Alabama

•MAXed Out - Santa Clara, California

•Mind & Iron - Seattle, Washington

•Sirius - South Hadley, Massachusetts

•Survey - Los Angeles

•West Virginia University Mountaineers - Morgantown, West Virginia

Prior to this final round of competition, the teams competed in Level 1, where robots had to return two known sample types but from an unknown location within 30 minutes without human control or the aid of Earth-based technologies, such as GPS or magnetic compassing. Since the challenge began in 2012, only seven teams have advanced to Level 2.

The Sample Return Robot Challenge, part of NASA's Centennial Challenges Program, aims to encourage innovation in robotics technologies relevant to space exploration and broader applications that benefit life on Earth. This event brings together tech-savvy citizens, entrepreneurs, educators and students to demonstrate robots that can locate and collect geologic samples from a wide and varied landscape without human control and within a specified time.

NASA's Centennial Challenges program is part of the agency's Space Technology Mission Directorate (STMD). STMD uses challenges to gather the best and brightest minds in academia, industry and government to drive innovation and enable solutions in important technology focus areas. WPI has hosted the Sample Return Robot Challenge since it began in 2012.

(Link: https://www.nasa.gov/press-release/nasa-holds-final-sample-return-robot-competition)

2015-16 Challenge Frequently Asked Questions (FAQ)

Below are FAQ regarding the Challenge Rules. Team Leaders of registered teams could submit questions about the rules by emailing challenge@wpi.edu. All new questions weree posted and answered in the online FAQ at http://challenge.wpi.edu.

F1. Can you describe in more detail how the prize money could be distributed?

Yes.

For Level 1:

All teams who successfully complete Level 1 will split $50,000, with a maximum of $5,000 per team.

• Prize money distributed in Level 1 becomes unavailable to be distributed for Level 2 prizes (i.e. they come from the same pool of $1.39M).

For Level 2:

1.The top 3 scoring teams will be determined by adding up the points associated with their collected samples. A minimum of 4 points must be scored.

2. The total amount of prize money available to be distributed will be determined based on the 1st place performer.

3. The judges will add the score of the top teams together.

4. Starting with 3rd place, divide the 3rd place score by the total points to get a percentage of the prize money 3rd place will receive. That percentage is then multiplied by the prize money available. If the amount is higher than the max set by their point level, they are given that maximum amount.

5. Repeat steps 3-4 until all 3 teams have been awarded money.

Below are some specific examples:

Example 1:

The top three teams score 10, 9, and 5 points respectively. Since the first place team scored 10 points, the total available to be distributed is $750,000 (see P8).

• 10+9+5 = 24 total points

• 5 pts divided by 24 total pts = 20.8%

• 20.8% of $750K = $156K

• For second place, 10+9=19. 9/19 = 47.4%. 47.4% of $650K is $308,100. Since the maximum a team can earn by scoring 9 points is $750K, they receive their determined amount of $308,100.

• For first place, $650K-$308,100 = $341,900. Again, since the maximum that can be earned by someone scoring 10 points is $750K, they receive all of their $341,900.

Example 2:

The top 2 teams score 4 and 5 points. No other teams score points in Level 2. Since the first place team scored 5 points, $250,000 is available to be distributed.

• 4+5 = 9 … 4/9 = 44.4% … 44.4% of $250K is $111,000. The second place team will win this.

• First place team will win $250,000 – $111,000 = $139,000.

Example 3:

• Only one team successfully completes Level 2 and they score 7 points. They will win $250,000.

F2. Will false samples be placed on the field?

No. We will not intentionally place any false samples on the field of play. For example, we would not place an out-of-spec tennis ball on the course of play and we will scan the entire course for debris that could potentially be misinterpreted as a sample prior to the start of the challenge attempts. However, if your robot collects an item that it though was a sample that isn't, it will count towards your non-sample mass.

F3. Will all the samples be on the course for Level 1?

No. The Level 1 course contains only the PCS and one easy sample.

F4. Will we have access to the samples once we arrive on-site?

Yes and no. Teams will be given some access to samples in the robot pit area with the following restrictions. For the Easy samples, all teams will have access to see, feel, touch, and calibrate to the actual samples we will use. For the Intermediate samples, all teams will have access to view the samples from a distance of no more than 15 meters in a controlled area. No teams will have any access to the hard samples until they identify them on the course.

F5. Can you provide more information of the exact nature of known samples or obstacles on the course?

Yes. While we are not suggesting you should purchase the items from the following retailers or this is the only place from which they can be purchased, below are links to the actual items referenced in the rules:

Orange Warning Fence (Field Boundary) – Please note we are showing this as a sample for anyone who may not know what we are describing. We will be seeking donors of this since there is a lot to purchase, so we may not know the final brand until we secure this. If what we end up getting for use is not available in retail quantities, we will do our best to get a sample to each team: http://www.homedepot.com/buy/building-materials/fencing/tenax-guardian-safety-fence/4-ft-x-100-ft-orange-warning-barrier-20640.html

Paint for easy samples: Rust-oleum Painter's Touch Ultra Cover (Paint + Primer), Gloss Grape 249113. UPC 020066187675

Sample of HSV color scale: http://i.stack.imgur.com/LC8Oh.png (240-60 means the blue, purple, red, orange side)

F6. Is the robot allowed to climb "immovable obstacles" on the terrain?

Yes. However, be aware of R5 if these behaviors have the potential to severely damage the obstacle.

F7. What kind of surfaces can we expect to encounter on the course?

You can expect to encounter firm ground and a variety of walkable surfaces. This would include turf, pavement, packed dirt, short grass, and possibly traversable rocks (i.e. gravel). You are not expected to move through loose mediums like sand, travel through water, or negotiate tall grass.

F8. Will people be allowed within view of the robot's sensors?

There will be no spectators inside the boundaries of the course or inside the boundary fencing. The only people allowed on the course will be event officials or individuals approved by the event for specific purposes (e.g. filming). Those allowed on the course will be clearly identified by their badge and clothing.

F9. Will the samples be placed on a table or buried in the ground?

No. The best effort will be made to have all samples placed on the surface of the course. Absolutely none will be buried or in water. In some cases, like with the tennis ball, it may be raised very slightly or contained in order to prevent it from rolling far from its location. An example would be placing a small rubber O-ring under the ball for it to sit on, so it is not sitting directly on the ground but extremely close to the surface.

F10. Can we get an unofficial inspection before our official one?

Yes. Any time before your challenge attempt or your robot is impounded your team may request an unofficial inspection. An inspector will review your robot for compliance and attempt to answer any questions you may have. A scale will also be available during this time. While these inspections are not final, our goal is to help make sure that every team that arrives with a robot is compliant with the rules and that does not stop them from competing.

F11. Can I move my robot from the on-deck area to the starting zone for Level 1 by driving it under its own power?

No.

F12. If my team only has one member at the event, will I be able to get assistance to move my robot?

Yes. You can ask for help from other teams or event officials. However, moving the robot is ultimately your responsibility and any damage that may occur during this process is your responsibility.

F13. Is the Home Beacon platform considered part of the starting platform?

No. This means that no part of your robot can start on or overhanging the Home Beacon platform. Additionally, any home beacon components not completely contained within the home beacon platform for the duration of the run will be considered part of the robot. Additionally, any samples that end up on or overhanging the Home Beacon platform will not count.

F14. Are teams allowed to mark the starting platform? How will we know it is ours?

Each starting platform will be painted a bright color and teams will know which platform they are starting on prior to each challenge attempt. In addition, teams are allowed to mark the platform as long as they do not permanently alter the platform and anything used to mark the platform is included in the robot mass, starts within the marked starting area, and violates no other rules. The Home Beacon starts on a separate platform directly behind the starting platform and is designed to aid competitors in this issue.

F15. How important is the separation of the samples from one another?

Obviously, when collecting samples from an unknown area, sterile handling would be extremely important for their scientific evaluation. For the purposes of this challenge, this is an important area but not a critical one we are looking to investigate. For example, teams may employ simpler methods like separate compartments within the same box or wrapping the samples individually and placing them in a single box. Judges will only be looking to ensure that the surfaces of any samples never come in contact with one another.

F16. How do we know if our samples are “easy and obvious to remove”?

The goal with this rule is to ensure that the judges can easily access the sample to determine if they have come in contact with other samples, to analyze the mass of all components returned, and to evaluate whether the samples are within the vertical projection of the starting platform. If a sample is incredibly difficult to access or cannot be accessed without moving the robot, the judges may deem those samples inaccessible and not count them.

Teams will be asked to provide documentation to the inspector that clearly describes how to access where any items are stored within the robot. Accessing these items may require tools, and these must be provided by the team to the inspector.

F17. What will be interpreted as "damage" to a sample?

A sample will be considered damaged if it has a permanent deformation or change in dimension.

F18. When my robot is paused, what exactly needs to stop?

When your robot is paused, it will most likely be done so for the safety of an event official on the course, or to allow another robot to pass in the case of multiple robots. For the safety aspect, it is critical that driving cease as well any outboard motion. It is not expected that your computing or sensing systems shut down, as it would likely be a tremendous time penalty for them to restart. However, any teams that wish to have items that continue moving during a pause must request and be approved for a pause exception. All decisions on what is or is not allowed are at the discretion of the judges.

F19. Can my robot send information to me or a computer outside the course, as long as I am not transmitting any information back?

Absolutely not. There is no communication in any direction allowed with the robot from anything not contained within the course, inspected before the run, and included in the starting size and mass of the robot during Level 1. While we understand this would be only to help you learn the robot's processes better, everyone has to understand it's a slippery slope. You are welcome to record data on-board. During Level 2, communication is limited to the Communication Update Periods (section 2.7.2.1)

F20. What does the 80kg mass of the robot apply to?

The 80kg mass applies to everything you as a competitor bring to the event and put on the starting platform to compete as part of your robot. This means it includes batteries, computers, e-stops, safety lights, and anything you might leave behind on the platform or on the course but needs to start with the robot. It does not, however, include the pause switch(es), the required payload in section 1.2, the home beacon, or any samples or materials collected during the run.

F21. Can we use a device onboard that has a GPS, accelerometer, compass, etc, as long as we don't use those features in our code or our challenge attempt at all?

Yes. We understand that it is tough today to purchase technology that doesn't include some of these components, even if they will not be used, and therefore we don't want to make the challenge even more difficult for anyone. If teams utilize devices with any of these disallowed technologies, the onus will be on the team to prove beyond a reasonable doubt that they are not using them during the competition. Teams should be aware that it will be the determination of judges and inspectors as to whether a team has proven compliance with these rules, and teams may be asked to modify or remove certain components to make their robot legal to compete.

F22. Are accelerometers allowed?

Yes, provided they comply with Section 1.3. Be aware that any sensors that utilize magnetic compensation will be disallowed.

F23. Are flying robots allowed?

Provided they comply with Section 1.3 and 1.4 of the rules.

F24. Can we leave objects/beacons/robots on the field at the end of our competition run?

Yes. All items will be removed by event officials at the end of each competition run.

F25. Can we have multiple robots on the field as long as they all start within the specified dimensions?

Yes, see also Section 1.4 of the rules.

F26. Can we use spring-damper systems for shock absorption and suspension?

Yes, provided it is a sealed system and could theoretically work in a vacuum, and complies with Section 1.3 of the rules.

F27. Are spawn allowed to communicate with each other and with the home beacon?

Yes, provided the communication meets all rules on allowed communication, disallowed technology rules, and FCC regulations.

F28. "The required payload may contain a strong magnetic source and frequency jammer to…." Couldn't this magnetic source directly interfere with R6?

The required payload is designed to aid judges and inspectors in enforcing the rules on allowed and disallowed technologies. Teams are required to submit documentation about their robots, beacons, and communication protocol approximately 6 months prior to the event with additional information on-site. Provided teams submit accurate and reasonable information about their plan and update any changes in a timely fashion, the required payload will not interfere with any allowed communication or technology.

F29. R6 states "any combination of electro-mechanical items provided by the team that assists their robot in identifying their starting platform" – does this mean there is no communication allowed between the home beacon and the robot(s)?

No, teams are allowed to communicate between their robot and home beacon (per C41), provided it complies will all Disallowed Technology rules and FCC regulations.

F30. Could clarification be provided on some of the following:

Is the 80,000 square meters roving area one long strip, round, square, rectangular? (E7)

• When will “limited topographical data” be provided? (Section 3)

• When will the satellite imagery, including starting zones, be released? (Section 3)

See rule E7. Approximately 6 months prior, teams will be provided with the imagery of the Level 1 and Level 2 courses. This will include “the area of interest for the pre-cached sample” as well as areas of interest of Level 2 samples.

F31. Could you clarify R17 and how the pause switch is supposed to work?

Yes. It is intended that the pause switch be a robust switch that, when triggered by an event official, sends a signal to the robot to pause all motion. When triggered again, another signal is sent which tells the robot it may resume motion. Among other things, since it is possible that a single team entry could require multiple pause switches (i.e. for spawn), the pause switch should not be designed such that an event official has to continually hold the button for the duration of the run or for the duration of the pause in order for the robot to remain in that state. We envision, as an example, a garage door opener as a simple potential solution. Teams should plan for these buttons to be robust, easy to use, and easy to hold because the onus is on the teams to ensure the switch works and remains active for the duration of the run.

F32. How will you deal with samples that may roll or move because of wind, being hit by a robot, or being hit by an event official?

We anticipate placing samples such that they will not move because of natural (i.e. wind) forces. However, in any situation where movement of a sample is caused by natural forces or robot interaction, the sample will not be replaced to its original spot and it will 'play as it lies'. In these cases, it is possible a sample will move closer to the boundary fence than 1 meter or become within 10 meters of another sample. In the event that a sample is hit or moved by an unnatural or non-robot force (i.e. event official) it will be replaced as close as possible to its original spot.

F33. What happens if an official inadvertently triggers an e-stop in the middle of a run?

We feel that the potential of an e-stop being accidentally or unintentionally triggered during a run is very, very small. The scenarios in which this could occur are hard to imagine and nearly impossible to name outcomes for at this time. If this were to happen in the challenge, on-site judges would convene to evaluate the situation and determine an appropriate resolution depending on the exact situation and circumstances. Some examples of potential outcomes we believe would be considered are: restarting the robot in base with the balance of time remaining and field in current status, restarting the entire run from base including removing and replacing any samples collected, or stopping the run and evaluating the team's performance based on the field as it currently stands. In no case will an inadvertent e-stop cause a disqualification of a team.

F34. Will you be providing additional information on the hard samples?

Yes. All fully registered teams will be provided with the potential rectilinear markings for the hard samples. Only samples with those markings are counted, but as per FAQ F2, we will not intentionally be placing false samples on the course.

F35. Are you planning to fully reveal the challenge location with either the topological data or satellite imagery?

Approximately six months from the event, we will release appropriate topographical data and imagery of the course to aid all competitors in successfully achieving the challenge. It is intended for this information to mimic the information a satellite or previous rover may have collected about the area. It is not our intention to reveal the actual location of the challenge at that time. While it is possible a team may be able to guess a potential location from the information, it will not be confirmed until teams arrive at WPI and are then transported to the event.

F36. Is it possible that the starting platforms will be set up as a “chute” entering the contest area with fencing on either side? Is it possible that the starting platform will be set up pointed directly at a close (< 2 m) snow fence?

Yes, it is possible the starting platforms will be setup with a ‘chute’ leading to an open area of the field. However, the robot will never be started pointed directly at a fence closer than 2 meters.

F37. Can rule E10 be interpreted to mean the hard sample could be 20x20x20cm?

At this time, we will not be providing any additional details or information on the hard samples. However, recall that the challenge is about searching for and identifying samples, so we do not anticipate any special manipulation being required to handle the hard samples versus the easy or intermediate samples.

F38. May I test my robot on-site prior to the event?

Absolutely no testing of robots will be allowed on-site prior to the event. The rules and regulations of the competition site directly prohibit various activities, specifically the operation of any sort of motorized vehicle. Violating any rules of the site would likely disrupt and delay the schedule of the entire event (a probable result of your actions is that the property owners rescind their offer to allow us to host the competition there) and thus doing so would be considered a violation of Section 4 of the Team Agreement.

F39. Will samples be placed inside any structures in the competition area?

No. Samples will not be placed inside any structures (i.e. buildings, trash cans, etc) on the course.

F40. May we use a solar tracking sensor?

There are no rules that prohibit the tracking of celestial bodies like the sun.

F41. What are the eligibility requirements for receiving awards? Is it open to the world this year, or still only primarily US citizens?

All teams are welcome to participate, but only US teams who meet the criteria outlined in the Team Agreement are eligible to win the $1.39M in prize money outlined in Sections 4.2 and 4.3 of the rules.

However, all officially registered teams who meet the deadlines and metrics set forth in the rules and Team Agreements will be eligible for the Technology Achievement Awards described in Section 4.1 of the rules.

F42. What happens to the prize distribution if a demonstration team (not prize eligible) places in the top three for Level 2?

If a team places in the top three of Level 2 but is ineligible for prize money per the team agreement, the money will be distributed to the top three prize eligible teams per the outlined structure in P8. An example is below.

Example:

The top 4 teams score 13, 8, 5, and 4 points respectively. However, the team who scored 10 points is a 'demonstration' team and not eligible for the prize. Therefore, the team who scored 8 is considered the top-scoring team for prize distribution and $750,000 is available for distribution per (P8).

• Start with 3rd place… 8+5+4=17… 4pts/17 total pts = 23.5%… 23.5% of $750K is $176,250 which the third place team will win.

• Second place is 8+5=13…. 5/13 = 38.5%… 38.5% of $573,750K is $220,894 which is what the second place team is awarded.

• $750,000-$176,250-$220,894 = $352,856 remains and is awarded to the top–scoring, prize-eligible team.

F43. R15 does not say what the fans are cooling. Are there any restrictions?

No. This year we do not restrict what fans can cool. However, onus will be on the team to prove any fans on their robot are not doing other actions besides cooling (like the sample collection).

F44. Previous years you suggested that the pause switch be a 'two-button pause'. Is that suggestion the same for this year?

Yes, along with description in the rules (R17), it is highly suggested, but not required, that you have a separate pause/unpause switch or a latching pause switch to aid the person controlling it in knowing what condition your robot is supposed to be in.

In the case of a single button, where the same button toggles pause/unpause, the event official may have no clear way of knowing the current state the robot should be in (i.e. did they push the button hard enough to unpause?). In the case of a two-button, latching, or other system that has other indicators, they know the state of their button or could hit 'unpause' again to ensure they had completed the action.

We feel this is the best situation for competitors to aid the event officials in doing their job efficiently and fairly.

F45. There are a lot of IMUs on the market now, but getting extremely hard to find without magnetometers on board. If we can show in our code where we are only using data from the accel/gyro sensors for our reference systems, will this be allowed?

Yes. The onus will be on the team to prove exactly what data is being accessed and how, and use of such devices will be under scrutiny of the Technical Review Committee and on-site judges. Bear in mind that per R14, the Required Payload is likely to contain a strong magnetic source which may interfere with the expected operation of your IMU even though you are not intentionally accessing those elements.

F46. Does having the Battery Management System (BMS) be “always on” (it draws some current even when the Mechanical E-Stop have cut power to the rest of the robot) violate the Mechanical E-Stop sections of R17?

The purpose of the E-stop is to prevent any injury to spectators, officials, or environment. Since a BMS actually can prevent such occurrence, by managing the status/condition of Lithium-based cells, this could be an allowed exception to this rule. Any teams wishing to make use of such a system must clearly outline and document the system in their required proposal. At the event, it would be imperative for the team to demonstrate that no other system receives power when the BMS is operating or when the E-Stop is activated.

F47. Are we allowed to place our home beacon in a specific alignment?

We will not regulate the orientation in which a teams places their home beacon on the home beacon platform, provided it complies with R9 and all other home beacon rules. However, please be aware of C34 and C45 when considering your home beacon setup (i.e. the home beacon must be secured to the platform in a remote location, will be transported by the event staff, and placed in conjunction with the starting platform in a random orientation).

F48. The Hard Sample Documentation indicates the inscription will be in contrasting paint. Does this indicate the main body of the sample will be painted?

This statement is meant to describe that the engraved portion of the hard sample is filled in with a color (using paint) to help distinguish it from the main body of the sample. It is not intended to imply or indicate whether or not the main body is painted.

F49. Can we use the tie down hoops to strap something in position that is not moving off the platform?

Per Rule C24 and the Starting Platform drawing (located in the Competition Area Info, Drawings, and Pictures page), all robots must be placed within the designated starting area/square. Since the attachment points ("tie down hoops") are located outside that square, being attached at the start would not be a legal starting configuration. The rules do not prevent being attached to the starting platform within the starting area before the challenge run commences or attaching to other areas after the start of the challenge run provided:

A.) It is non-destructive to the platform (creating a permanent mark, alteration, or deformation)

B.) It complies with all other robot starting rules

Please note that the starting platform is designed to hold a robot at the start of a challenge run and support reentry of the robot during the run only.

F50. Can you provide further clarification on P9 and the Level 2 tiebreakers?

Yes. Consider these scenarios in Level 2:

Three teams score 8 points each, another scores 7, and another scores 5. ONLY the three teams who scored 8 points will receive prize money. They will evenly split $250,000.

• Two teams score 8 points each, another scores 7, and another scores 5. Each of the teams who scored 8 points receive 34.8% of the $250,000 ($87,000) and the team who scored 7 receives 30.4% ($76,000).

• One team scores 8 points, two teams score 7 points each, and another scores 5. The team who scored 8 receives 36.4% ($91,000) and each of the teams that scored 7 receives 31.8% ($79,500)

• Four teams score 8 points and another scores 7 points. The four teams who scored 8 points will receive prize money. They will evenly split $250,000.

• One team scores 8 points and 3 teams score 7 points. The team that scored 8 receives 53.3% ($133,250). The three teams who score 7 evenly split 46.7% of the $250,000 ($38,916.67 per team).

F51. In rules E8, an orange fence is said to mark borders of the challenge area. Does the fence also mark the edge of the water hazard for Level 2?

Our intention is not to require teams to traverse through water during their challenge attempt (See F7) or be able to specifically detect water. The challenge course is designed to represent conditions an autonomous robot might find while exploring a lunar or Martian environment and ensure it can distinguish between areas which are safe to explore and others which are not. The fence will mark boundary areas of water where no other undrivable condition marks the water area. For example, a steady-sloped beach leading into water would be marked with fencing, whereas a steep cliff which drops off into water may not be.

F52. Are teams allowed to use adhesives in their sample collection design?

While there is no rule that strictly prohibits this, teams should be aware that they are required to return “undamaged” samples which are “easy and obvious to remove” from the robot. In this case, a sample would be considered damaged if any adhesive were obviously left on the sample or any part of the sample (like paint) comes off during the collection, storage, or removal process.

F53. Do samples need to be in separate containers or are they able to be in an open space as long as they do not make contact with another object?

There is no rule that prohibits this, but the onus will be on the team to prove there is no situation during which they could come in contact during a challenge attempt. If this is not obvious from the robot design or demonstration, the judges will be required to evaluate whether it was likely to have happened and score the run accordingly using their best judgment.

F54. If our robot is paused on a hillside with potential to roll downhill, is it permitted for the motors to use a controller to actively hold their position?

Yes. Rule R17 indicates that all MOTION must stop, not power. Pausing the robot allows time for the judges to evaluate potential rules violations or right-of-way situations. Although the judges may not E-Stop a robot that slowly moved down a hill under pause, it is preferable that robots do not move during a pause.

F55. There seems to be potential safety concerns with utilizing flyers. How will the competition staff deal with these issues?

Flyers are part of the robot/home beacon, meaning they are subject to all the robot/home beacon rules and the team must be able to prove that the robot/home beacon as a whole (including the flyer) is capable of being operated safely and meeting all rules.

For example, the portion of the robot to which the flyer is attached will be subject to being paused or e-stopped if it were to cross the orange fence or cause damage to the course. The onus would be on any team using a flyer to show the flyer can be safely managed in any weather conditions and during required pause and e-stop situations. Event officials will monitor all robot components for dangerous conditions and for robot-to-robot contact if there is more than one team's robot on the course.

F56. Is the flyer considered a 'spawn' of the part of the robot to which it is tethered?

No, the flyer is considered part of the robot as a whole and part of the portion of the robot to which it is tethered. If it was a spawn, it would be required to comply with rules like maximum e-stop height. Instead, by tethering the flying portion of the robot, elements like the e-stop and safety light are on the base portion and are not required to be on the flyer itself. However, since the flyer must e-stop when the robot part it is tethered to is e-stopped, it must have a powered connection from the base (since e-stops must be hardware- and not software-based)

F57. What does vertical flight mean? Are there any restrictions?

Per rule R3, the maximum height of the robot is 4m, meaning at no point can the robot fly higher than 4m. However, there is no limit to the length of the tether. Just like other robot components, it is the role of the team to ensure the robot does not violate the rule. Additionally, the 2m/s rule R4 applies to traversal across the course, meaning travel parallel to the ground. Vertical speed is not limited (just like the speed an arm or other component of a robot is not limited). If the flyer is associated with the home beacon it must comply with the physical restrictions of R9.

F58. Is there a limit to the number of flying components a robot may have?

Provided they meet all other robot rules, there is no limit. As long as each flyer is tethered (physically and, if powered, electrically) to part of the robot (and spawn are considered part of the robot) there is no issue.

F59. What happens to a flyer when the part of the robot is attached to is e-stopped or the entire robot is paused?

As always, the onus is on the teams to prove that when these buttons are pressed, all portions of the robot comply. In the case of a safe e-stop (graceful shutdown), a heavier-than-air flyer should be able to have a controlled and safe landing executed by the team. In the case of an unsafe e-stop (emergency situation), power to the entire robot must be cut immediately including to the flyer. In the case of a pause, the entire robot must stop motion within 1 second. However, it is highly suggested that robots with a flying component request a pause exemption to allow more than 1 second for the flyer to land or to allow it to continue to fly provided it would not inhibit access to the robot by event officials.

F60. Is the robot allowed to move during the setup time (C34), e.g. moving its arm and steering motors to initialize encoders as long as it does not leave the area of the starting platform?

Yes.

F61. During a Communication Update Period, is arbitrary interaction with the robot via a console window (e.g. a Linux terminal window on a monitor connected to the robot) allowed? For example, one might enter commands into a console window to stop the current software, examine or edit some configuration files or code, then resume code execution. I am trying to determine whether "Download new code to the robot" literally means "Copy code from a USB drive, then run the code," or whether it can be interpreted as "Make whatever software modifications you deem fit, as long you don't modify the hardware."

(Link: http://wp.wpi.edu/challenge/2012-13-challenge-documents-information/2015-16-frequently-asked-questions-faq/)

Occupational Safety and Health Administration (OSHA) Health and Safety in Robot Environments

Industrial robots are programmable multifunctional mechanical devices designed to move material, parts, tools, or specialized devices through variable programmed motions to perform a variety of tasks. Robots are generally used to perform unsafe, hazardous, highly repetitive, and unpleasant tasks. They have many different functions such as material handling, assembly, welding, machine tool load and unload functions, painting, spraying, and so forth.

Studies indicate that many robot accidents occur during non-routine operating conditions, such as programming, maintenance, testing, setup, or adjustment. During many of these operations the worker may temporarily be within the robot's working envelope where unintended operations could result in injuries.

OSHA Instruction PUB 8-1.3 SEP 21, 1987 Office of Science and Technology Assessment

Subject: Guidelines for Robotics Safety

A. Purpose. This instruction provides guidelines to OSHA compliance officers, employers, and employees for the safe operation and use of robots and robotic systems.

B. Scope. This instruction applies OSHA-wide.

C. Action. Regional Administrators and Area Directors shall provide copies of Appendix A to the appropriate personnel and shall ensure that copies are available for distribution to the public upon request.

D. Federal Program Change. This instruction describes a change in the Federal Program for which a State response is not required. Each Regional Administrator, however, shall:

> 1. Ensure that this change is promptly forwarded to each State designee.2. Explain the technical content of this change to the State as requested.3. Inform the State designees

that they are encouraged to make available Appendix A or similar guidelines to State plan personnel and appropriate employers.

E. State Consultation Projects.

1. Regional Administrators shall forward a copy of this instruction to each consultation project manager and explain the technical content where requested.2. Consultation Project Managers shall ensure that the information in Appendix A is provided to appropriate employers and ensure that copies are available for distribution to the public upon request.

The purpose of this instruction is to inform OSHA compliance officers and employers and employees about safety concerns that have arisen with the growing use of robotics systems in manufacturing. Industrial robots can be used to perform hazardous tasks but in doing so they can create new hazards. With the burgeoning use of robots in industry, it is feared that without adequate guarding and personnel training, injury rates for employees working with robots may increase.

Current guidelines for robot safety include the American National Standards Institute (ANSI) ANSI-RIA R15.06-1986, "American National Standard for Industrial Robots and Robot Systems - Safety Requirements," and the National Institute for Occupational Safety and Health (NIOSH) December, 1984 Alert "Request for Assistance in Preventing the Injury of Workers by Robots." Copies of the ANSI Standard are available from the American National Standards Institute, Inc., 1430 Broadway, New York, NY 10018. The NIOSH Alert was prepared by its Division of Safety Research, 944 Chestnut Ridge Road, Morgantown, WV 26505.

This instruction provides general introductory material describing the features of robots and robotics systems which present unusual hazards and will describe some of the more common safety systems employed to alleviate these hazards. The ANSI Standard defines consensus provisions for the construction, reconstruction, modification, installation, safeguarding, care, testing, and start-up of robots and robotics systems as well as training for robot and robotics systems operations and maintenance personnel. The NIOSH Alert contains safety recommendations that are based on its field evaluation of the first identified robot-related fatality in the United States.

Introduction

Robots are reprogrammable, multifunctional, mechanical manipulators that typically employ one or more means of power: electromechanical, hydraulic, or pneumatic. Industrial robots have been used chiefly for spray painting, spot-welding, and transfer and assembly tasks. A robot performs its tasks in a physical area known as the robot operating work envelope. This work envelope is the volume swept by all possible programmable robot movements. This includes the area where work is performed by robot tooling.

A robot can have one or more arms which are interconnected sets of links and powered joints. Arms are comprised of manipulators which support or move wrists and end-effectors. An end-effector is an accessory tool specifically designed for attachment to a robot wrist to enable the robot to perform its intended task. Examples of end-effectors include grippers, spot-weld guns, and spray paint guns. The ANSI R15.O6-1986 Standard defines an industrial robot system as that which includes industrial robots, end-effectors, and any equipment, devices and sensors required for the entire robot system to perform its tasks.

OSHA Instruction PUB 8-1.3 SEP 21, 1987 Office of Science and Technology Assessment

Most robots are set up for an operation by the teach-and-repeat technique. In this technique, a trained operator (programmer) typically uses a portable control device (commonly referred to as a teach pendant) to manually key a robot and its tasks. Program steps are of the up-down, left-right, in-out, and clockwise-counterclockwise variety. Robot speeds during these programming sessions are required to be slow. The ANSI Standard currently recommends that this slow speed should not exceed 10 in/sec (250 mm/sec).

The very nature of robotics systems operations has introduced a new type of employee into the industrial workplace, the corrective maintenance worker. This individual is normally present during all operations of a robotics system and is responsible for assuring continuing operation - adjusting speeds, correcting grips, and freeing jam-ups. The corrective maintenance worker may also be the trained programmer who guides a robot through the teach-and-repeat technique. It is necessary for this individual to be near the robot from time to time, which raises concerns about his or her safety and the safety of other workers who may also be exposed.

Recent studies in Sweden and Japan indicate that many robot accidents do not occur under normal operating conditions but rather during programming, adjustment, testing, cleaning, inspection, and repair periods. During many of these operations, the operator, programmer or corrective maintenance worker may temporarily be within the robot work envelope while power is available to moveable elements of the robot system.

This guideline describes some of the elements of good safety practices and techniques used in the section and installation of robots and robot safety systems, control devices, robot programming and employee training. A comprehensive list of safety requirements is provided in the ANSI R15.06-1986 Standard.

TYPICAL ACCIDENTS

The following are documented accidents involving robots that occurred recently in Japan, Sweden, and the United States:

- A worker attempted to remove an imperfectly formed piece from a conveyor with both hands while the operation limit switch of a material feed and removal robot remained in its active position. The worker's back was forced against the robot.- After adjusting a metal shaving machine, an operator was caught between the machine and a just-extended arm of a material feed and removal robot.

- A welding robot went functionally awry and its arm flung a worker against another machine.- A worker removed the cover of an operating assembly robot to retrieve a fallen part and caught his hand in the robot's drive train.- A worker attempted to retrieve a part needed in an ongoing assembly without shutting off an assembly robot's power supply. His hand was caught between the robot's arm and the unit being assembled.- A robot's arm functioned erratically during a programming sequence and struck the operator.- A fellow employee accidentally tripped the power switch while a maintenance worker was servicing an assembly robot. The robot's arm struck the maintenance worker's hand.- An operator performing troubleshooting on a metal plater robot maneuvered the robot's arm into a stopped position. This triggered the robot's emergency stop mode which delayed venting of a pneumatic air storage device. When the return mode was activated, the robot's arm moved suddenly and jammed the operator's thumb against a structural member.- An automatic welder robot operator made a manual adjustment without stopping the robot. He was hit in the head by one of the robot's moving parts when the next batch of weldments arrived.- A materials handling robot operator entered a robot's work envelope during operations and was pinned between the back end of the robot and a safety pole.

Safety Systems

The proper selection of an effective robotics safety system must be based on hazard analysis of the operation involving a particular robot. Among the factors to be considered in such an analysis are the task a robot is programmed to perform, the start-up and the programming procedures, environmental conditions and location of the robot, requirements for corrective tasks to sustain normal operations, human errors, and possible robot malfunctions. Sources of robot hazards include:

1. Human errors;
2. Control errors;
3. Unauthorized access;
4. Mechanical hazards;
5. Environmental hazards;

6. Electric, hydraulic, and pneumatic power sources.

An effective safety system protects operators, engineers, programmers, maintenance personnel, and others who could be exposed to hazards associated with a robot's operation. A combination of methods may be used to develop an effective safety system. Redundancy and backup systems are recommended, particularly if a robot can create serious hazardous conditions.

Guarding Methods:

1. Interlocked Barrier Guard

This is a physical barrier around a robot work envelope incorporating gates equipped with interlocks. These interlocks are designed so that all automatic operations of the robot and associated machinery will stop when any gate is opened. Restarting the operation requires closing the gate and reactivating a control switch located outside of the barrier. A typical practical barrier is an interlocked fence designed so that access through, over, under, or around the fence is not possible when the gate is closed.

2. Fixed Barrier Guard

A fixed barrier guard is a fence that requires tools for removal. Like the interlocked barrier guard, it prevents access through, over, under, or around the fence. It provides sufficient clearance for a worker between the guard and any robot reach, including parts held by an end-effector, to perform a specific task under controlled conditions.

3. Awareness Barrier Device

This is a device such as a low railing or suspended chain that defines a safety perimeter and is intended to prevent inadvertent entry into the work envelope but can be climbed over, crawled under, or stepped around. Such a device is acceptable only in situations where a hazard analysis indicates that the hazard is minimal and inter locked or fixed barrier guards are not feasible.

Interlocked or fixed barrier guards provide a positive protection needed to prevent worker exposure to robotic systems hazards.

4. Presence Sensing Devices

The presence detectors that are most commonly used in robotics safety are pressure mats and light curtains. Floor mats (pressure sensitive mats) and light curtains (similar to arrays of photocells) can be used to detect a person stepping into a hazardous area near a robot. Proximity detectors operating on electrical capacitance, ultrasonics, radio frequency, laser, and television principles are currently undergoing reliability testing in research laboratories because of recognized limitations in their capability of detecting the presence of personnel. Although some of these devices are already available in the safety equipment marketplace, care must be used in their selection to insure adequate safety and reliability. At this time, such proximity detectors are not recommended for such use unless a specific analysis confirms their acceptability for the intended use.Effective presence sensing devices stop all motion of the robot if any part of a worker's body enters the protected zone. Also, they are designed to be fail-safe so that the occurrence of a failure within the device will leave it unaffected or convert it into a mode in which its failed state would not result in an accident. In some cases this means deactivation of the robot. Factors which are considered in the selection of such devices include spatial limitations of the field, environmental conditions affecting the reliability of the field, and sensing field interference due to robot operation.

5. Emergency Robot Braking

Dangerous robot movement is arrested by dynamic braking systems rather than simple power cut-off. Such brakes will counteract the effects of robot arm inertia. Cutting off all power could create hazards such as a sudden dropping of a robot's arm or flinging of a workpiece.

6. Audible and Visible Warning Systems

Audible and visible warning systems are not acceptable safeguarding methods but may be used to enhance the effectiveness of positive safeguards. The purposes of audible and visible signals need to be easily recognizable.

Control Devices: The following characteristics are essential for control devices:

1. The main control panel is located outside the robot system work envelope in sight of the robot.

2. Readily accessible emergency stops (palm buttons, pull cords, etc.) are located in all zones where needed. These are clearly situated in easily located positions and the position identifications are a prominent part of personnel training. Emergency stops override all other controls.

3. The portable programming control device contains an emergency stop.

4. Automatic stop capabilities are provided for abnormal robot component speeds and robot traverses beyond the operating envelope.

5. All control devices are clearly marked and labeled as to device purpose. Actuating controls are designed to indicate the robot's operating status.

6. Controls that initiate power or motion are constructed and guarded against accidental operation.

7. Each robot is equipped with a separate circuit breaker that can be locked only in the "off" position.

8. User-prompt displays are used to minimize human errors.

9. The control system for a robot with lengthy start-up time is designed to allow for the isolation of power to components having mechanical motion from the power required to energize the complete robot system.

10. Control systems are selected and designed so that they prevent a robot from automatically restarting upon restoration of power after electrical power failure. The systems also prevent hazardous conditions in case of hydraulic, pneumatic or vacuum loss or change.

11. A robot system is designed so that it could be moved manually on any of its axes without using the system drive power.

12. All control systems meet OSHA 29 CFR 1910 Subpart S standards for electrical grounding, wiring, hazardous locations, and related requirements.

Installation, Maintenance And Programming: Good installation, maintenance, and programming practices include the following:

1. The robot is installed in accordance with the manufacturer's guidelines and applicable codes. Robots are compatible with environmental conditions.

2. Power to the robot conforms to the manufacturer's specifications.

3. The robot is secured to prevent vibration movement and tip over.

4. Installation is such that no additional hazards are created such as pinch points with fixed objects and robot components or energized conductor contact with robot components.

5. Signs and markings indicating the zones of movement of the robot are displayed prominently on the robot itself and, if possible, on floors and walls.

6. Stops are placed on the robot system's axes to limit its motions under rated load and maximum speed conditions.

7. A lock-out procedure is established and enforced for preventive maintenance or repair operations.

8. The robot manufacturer's preventive maintenance schedule is followed rigorously.

9. A periodic check of all safety-critical equipment and connections is established.

10. Stored energy devices, such as springs and accumulators, are neutralized before robot servicing.

11. Only programmers have access to the work envelope and full control of the robot when it is in the teach mode.

12. All robot motion initiated from a teach pendant used by a programmer located within the robot work envelope is subject to the current ANSI slow speed recommendation of 10 in/sec (250 mm/sec).

Training: Effective accident prevention programs include training. Some points to be considered in training programs include:

1. Managers and supervisors in facilities that use robots are trained in the working aspects of robots so that they can set and enforce a robotics safety policy from an informed viewpoint.

2. The employer insures that his or her company has a written robotics safety policy that has been explained to all personnel who will be working with robots. This safety policy states by name which personnel are authorized to work with robots.

3. Robot programming and maintenance operations are prohibited for persons other than those who have received adequate training in hazard recognition and the control of robots.

4. Robot operators receive adequate training in hazard recognition and the control of robots and in the proper operating procedure of the robot and associated equipment.

5. Training is commensurate with a trainee's needs and includes the safeguarding method(s) and the required safe work practices necessary for safe performance of the trainee's assigned job.

6. If it is necessary for an authorized person to be within the work envelope while a robot is energized, for example during a programming sequence, training is provided in the use of slow robot operation speeds and hazardous location avoidance until the work is completed. Such training also includes a review of emergency stops, and a familiarization with the robot system's potentially hazardous energy sources.

(Link: https://www.osha.gov/SLTC/robotics/additionalinformation.html)

(Link: https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=DIRECTIVES&p_id=1703)

National Consensus

Note: These are NOT OSHA regulations. However, they do provide guidance from their originating organizations related to worker protection.

American National Standards Institute (ANSI)

R15.06-1999, Industrial Robots and Robot Systems - Safety Requirements. Provides requirements for industrial robot manufacture, remanufacture and rebuild; robot system integration/installation; and methods of safeguarding to enhance the safety of personnel associated with the use of robots and robot systems. This second review further limits the potential requirements for any retrofit of existing systems, revises the description of control reliable circuitry, and reorganizes several clauses to enhance understanding.

TR R15.106-2006, Technical Report on Teaching Multiple Robots. **Robotics Industries Association (RIA)**. Provides additional safety information relative to teaching (programming) multiple industrial robots in a common safeguarded space in an industrial setting. It supplements the ANSI/RIA R15.06-1999 robot safety standard.

B11.TR3-2000, Risk Assessment and Risk Reduction - A Guide to Estimate, Evaluate and Reduce Risks Associated with Machine Tools. Provides a means to identify hazards associated with a particular machine or system when used as intended, and provides a procedure to estimate, evaluate, and reduce the risks of harm to individuals associated with these hazards under the various conditions of use of that machine or system.

International Organization for Standardization (ISO)

ISO 10218-1:2006, Robots for industrial environments - Safety requirements - Part 1: Robot. Robotics Industries Association (RIA). Specifies requirements and guidelines for the inherent safe design, protective measures, and information for use of industrial robots. It describes basic hazards associated with robots, and provides requirements to eliminate or adequately reduce the risks associated with these hazards.

◦Note: ISO 10218-1:2006 does not apply to non-industrial robots although the safety principles established in ISO 10218 may be utilized for these other robots. Examples of non-industrial robot applications include, but are not limited to: undersea, military and space robots; teleoperated manipulators; prosthetics and other aids for the physically impaired; micro-robots (displacement <1 mm); surgery or healthcare; and service or consumer products.

Canadian Standards Association (CSA)

Z434-03, Industrial Robots and Robot Systems. Applies to the manufacture, remanufacture, rebuild, installation, safeguarding, maintenance and repair, testing and start-up, and personnel training requirements for industrial robots and robot systems.

American Welding Society (AWS)

D16.1M/D16.1, Specification For Robotic Arc Welding Safety. Identifies hazards involved in maintaining, operating, integrating, and setting up arc welding robot systems.

(Link: https://www.osha.gov/SLTC/robotics/standards.html)

Universities with a Robotics Program

Brown University : http://www.cs.brown.edu/research/robotics/

Cal Poly Pomona : http://www.csupomona.edu/~ece/rover/index.html

Caltech : http://robby.caltech.edu/

Caltech : http://www.coro.caltech.edu/

Carnegie-Mellon University : http://www-2.cs.cmu.edu/~multirobotlab/

Carnegie-Mellon University : http://www-2.cs.cmu.edu/~cyberscout/

Carnegie-Mellon University : http://www.frc.ri.cmu.edu/

Carnegie-Mellon University : http://www-2.cs.cmu.edu/~illah/lab.html

Colorado School of Mines : http://egweb.mines.edu/cardi/

Columbia University : http://www1.cs.columbia.edu/robotics/

Cornell University : http://robotics.cornell.edu/

Dartmouth College : http://www.cs.dartmouth.edu/~brd/robotics.html

Drexel University : http://itcsl.cs.drexel.edu/

Florida A&M University/FSU : http://www.eng.fsu.edu/~panini/robot/

Florida International University : http://www.eng.fiu.edu/me/robotics/

Georgia Tech : http://www.cc.gatech.edu/ai/robot-lab/

Indiana University : http://www.indiana.edu/~roboclub/

Johns Hopkins University : http://bach.ece.jhu.edu/~etienne/labweb/

Johns Hopkins University : http://www.cs.jhu.edu/CIRL/

Johns Hopkins University : http://robotics.me.jhu.edu/~www/

Kansas State University : http://www.cis.ksu.edu/~dag/robotics/home.shtml

Long Beach City College : http://elect.lbcc.edu/pages/programs.html

MIT : http://www.ai.mit.edu/

MIT : http://robots.mit.edu/

New Mexico Institue of Mining & Technology : http://www.ee.nmt.edu/~isrg/

North Carolina State University : http://www2.ncsu.edu/CIL/CARL/index.htm

Northwestern Polytechnic University, Humanoid Project : http://www.npu.edu/humanoidproject/

Ohio State University : http://eewww.eng.ohio-state.edu/

Oregon State University : http://eecs.oregonstate.edu/education/about.html

Portland State University : http://www.ece.pdx.edu/~mperkows/ML_LAB/index.html

Rice University : http://www.cs.rice.edu/CS/AIRobotics/

Southern Illinois University, Edwardsville : http://roboti.cs.siue.edu/

Stanford University : http://sun-valley.stanford.edu/arl.html

Stanford University : http://robotics.stanford.edu/home.html

Stanford University : http://www-cdr.stanford.edu/Touch/touchpage.html

Tennessee State University : http://www.tnstate.edu/imrl/

Texas A&M University : http://parasol-www.cs.tamu.edu/dsmft/

U.S. Air Force Academy : http://www.usafa.af.mil/

UC Berkeley : http://robotics.eecs.berkeley.edu/

UC Berkeley : http://www.me.berkeley.edu/hel/

UC San Diego : http://www-rohan.sdsu.edu/~tarokh/lab/

UC San Diego : http://cvrr.ucsd.edu/

UC Santa Cruz : http://www.cse.ucsc.edu/labs/taoswap/

University of Arizona : http://www.ame.arizona.edu/

University of Cincinnati : http://www.robotics.uc.edu/

University of Florida : http://www.mil.ufl.edu/

University of Hawaii : http://www.eng.hawaii.edu/~asl/

University of Houston (Downtown campus) :
http://www.uhd.edu/academic/colleges/sciences/engineeringtech/

University of Houston (Main and Clear Lake campuses) : http://www.egr.uh.edu/

University of Houston (Main and Clear Lake campuses) : http://nas.cl.uh.edu/

University of Idaho : http://www.mrc.uidaho.edu/cisr/

University of Maryland : http://www.cs.umd.edu/projects/amrl/

University of Maryland : http://www.ssl.umd.edu/

University of Massachusetts, Amherst : http://dis.cs.umass.edu/

University of Massachusetts, Amherst : http://www-robotics.cs.umass.edu/lpr.html

University of Michigan, Ann Arbor : http://www.engin.umich.edu/research/mrl/index.html

University of Minnesota : http://www.cs.umn.edu/Research/airvl/

University of Missouri-Columbia : http://sun16.cecs.missouri.edu/

University of Nebraska-Lincoln : http://robots.unl.edu/index.html

University of New Hampshire : http://www.ece.unh.edu/robots/rbt_home.htm

University of New Mexico : http://vlab.unm.edu/

University of New Mexico : http://pursue.unm.edu/robotics/

University of New Mexico : http://www-mep.unm.edu/html/radds.html

University of New Mexico : http://www.eece.unm.edu/%7Echsmith/raiv.html

University of Notre Dame : http://www.nd.edu/~airolab/

University of Notre Dame : http://www.nd.edu/~isall/

University of Oklahoma : http://www.amerobotics.ou.edu/intro.html

University of Pennsylvania : http://www.grasp.upenn.edu/

University of Rochester : http://www.cs.rochester.edu/users/faculty/brown/lab.html

University of South Florida : http://www.csee.usf.edu/robotics/crasar/

University of Southern California : http://www-robotics.usc.edu/

University of Southern California : http://www-robotics.usc.edu/~embedded/

University of Tennessee, Knoxville : http://www.cs.utk.edu/~parker/Distributed-Intelligence-Lab/index.html

University of Tennessee, Knoxville : http://imaging.utk.edu/

University of Texas, Austin : http://www.robotics.utexas.edu/rrg/

University of Texas, Dallas : http://www.utdallas.edu/dept/eecs/

University of Utah : http://www.cs.utah.edu/vision/vision_robotics.html

University of Utah : http://www.cs.utah.edu/~jmh/VETO.html

University of Washington, Bothell : http://faculty.washington.edu/cfolson/mapping.html

University of Washington, Seattle : http://brl.ee.washington.edu/

University of Washington, Seattle : http://www.cs.washington.edu/ai/Mobile_Robotics/

University of Wisconsin, Madison : http://robios8.me.wisc.edu/

Utah State University : http://www.csois.usu.edu/

Vanderbilt University : http://eecs.vanderbilt.edu/CIS/IRL/

Vanderbilt University : http://eecs.vanderbilt.edu/cis/CRL/index.html

Vanderbilt University : http://129.59.79.44/index.html

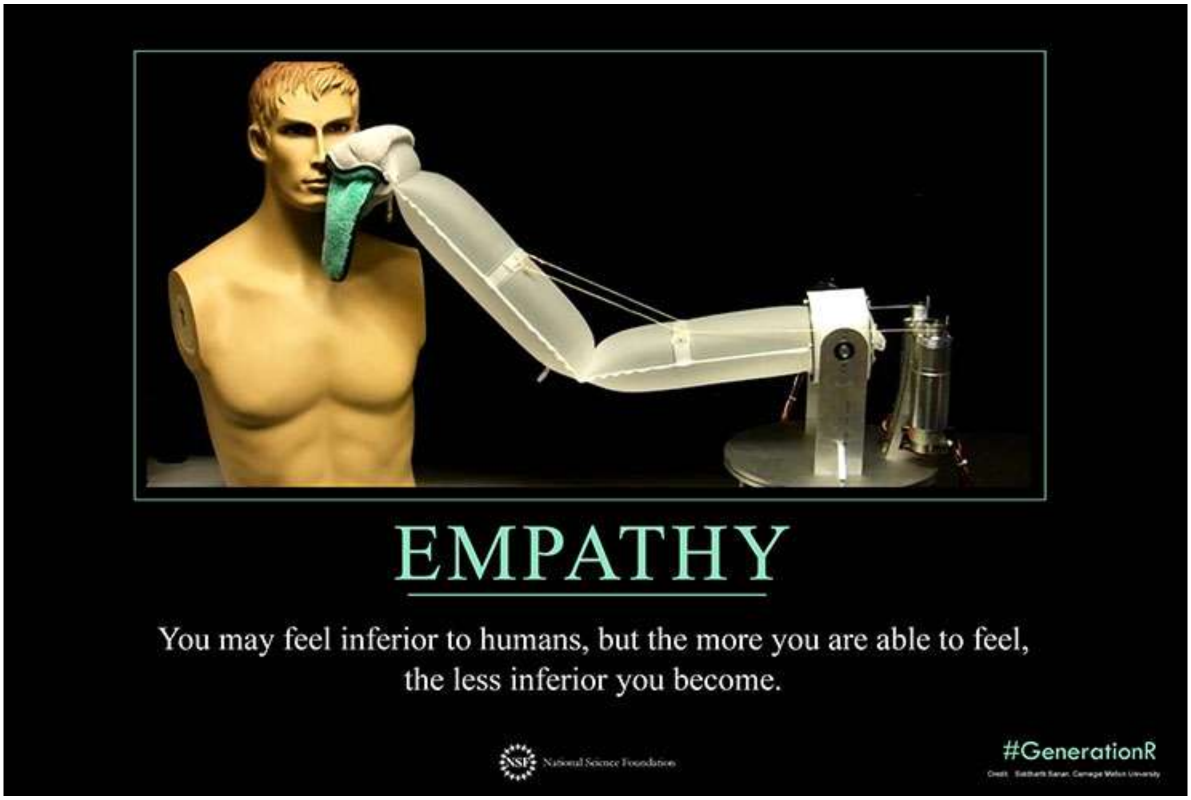
Villanova University : http://www.csc.vill.edu/lab/special.html

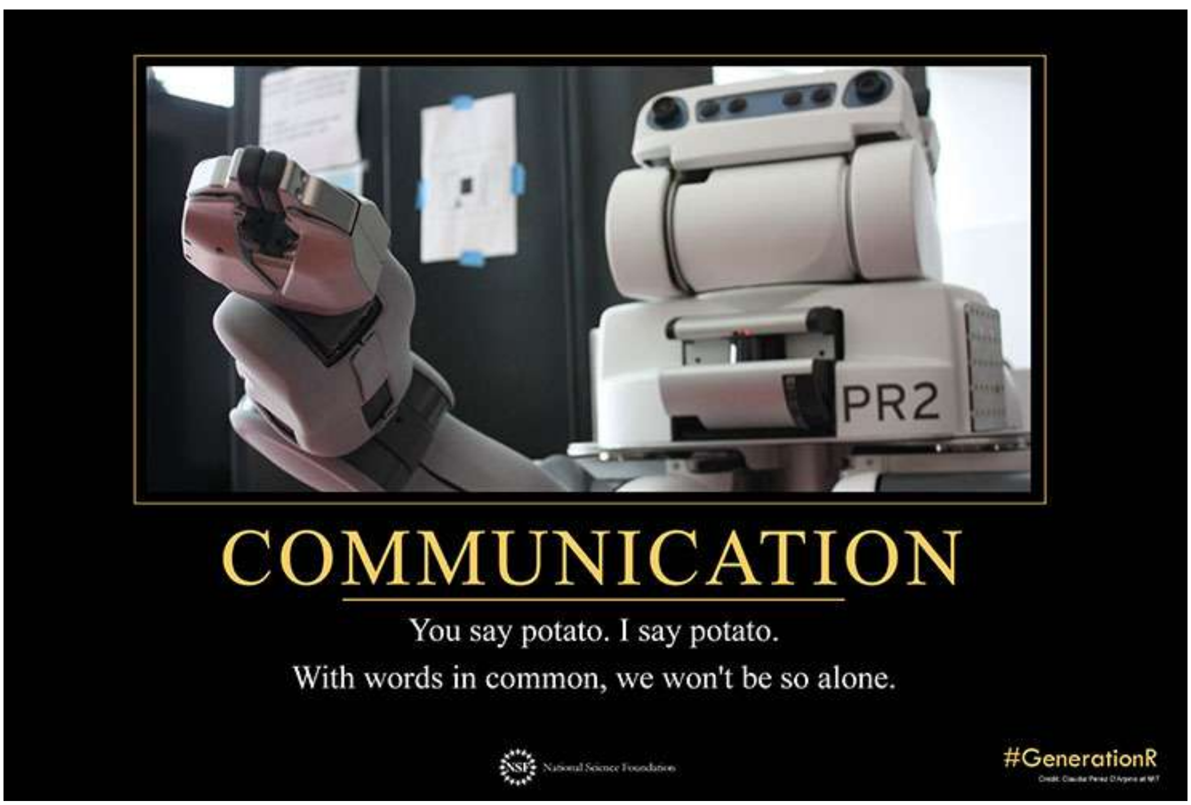
Virginia Tech : http://armyant.ee.vt.edu/avt/

Wellesley University : http://www.wellesley.edu/Physics/robots/studio.html

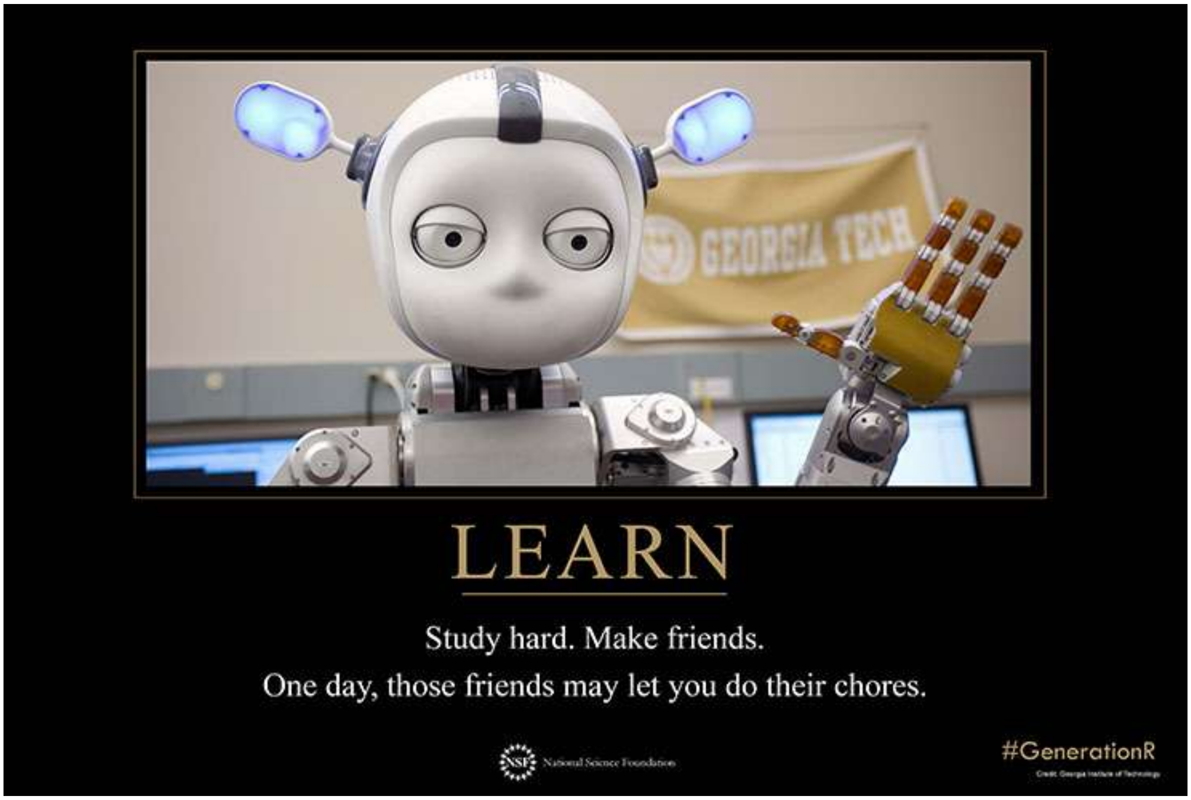
(Link: https://robotics.nasa.gov/students/robo_u.php)

Robot Posters


EMPATHY
You may feel inferior to humans, but the more you are able to feel, the less inferior you become.
National Science Foundation
#GenerationR


PR2
COMMUNICATION
You say potato. I say potato.
With words in common, we won't be so alone.
National Science Foundation
#GenerationR


INDEPENDENCE
When you walk on your own, no one can push you down.
Except bigger robots.
National Science Foundation
#GenerationR


GEORGIA TECH
LEARN
Study hard. Make friends.
One day, those friends may let you do their chores.
National Science Foundation
#GenerationR
Credit: Georgia Institute of Technology


POWER
If you store enough power in a small space, you can fly.
But only up to 400 feet per federal regulations.
National Science Foundation
#GenerationR


STRENGTH
The strongest robot is the one
that knows when to be gentle.
National Science Foundation
#GenerationR
Credit: Personal Robots Group, MIT Media Lab


SUSTAINABILITY
Reshape yourself to achieve your full potential.
Then, dive headlong into an organic solvent and dissolve.
National Science Foundation
#GenerationR


SUSTAINABILITY
Reshape yourself to achieve your full potential.
Then, dive headlong into an organic solvent and dissolve.
National Science Foundation
#GenerationR


TEAMWORK
Because there is no "i" in robot.
And I, Robot is fiction.
National Science Foundation
#GenerationR


VISION
Take time to appreciate your surroundings.
Avoid the embarrassment of mistaking people for chairs.
National Science Foundation
#GenerationR

Glossary for Robotics and Robotic Systems

Actuator

A power mechanism used to effect motion of the robot; a device that converts electrical, hydraulic, or pneumatic energy into robot motion.

Application Program

The set of instructions that defines the specific intended tasks of robots and robot systems. This program may be originated and modified by the robot user.

Attended Continuous Operation

The time when robots are performing (production) tasks at a speed no greater than slow speed through attended program execution.

Attended Program Verification

The time when a person within the restricted envelope (space) verifies the robot's programmed tasks at programmed speed.

Automatic guided-vehicle systems

Aare advanced material-handling or conveying systems that involve a driverless vehicle which follows a guide-path.

Automatic Mode

The robot state in which automatic operation can be initiated.

Automatic conveyor and shuttle systems

Are comprised of various types of conveying systems linked together with various shuttle mechanisms for the prime purpose of conveying materials or parts to prepositioned and predetermined locations automatically.

Automatic Operation

The time during which robots are performing programmed tasks through unattended program execution.

Automatic storage and retrieval systems

Are storage racks linked through automatically controlled conveyors and an automatic storage and retrieval machine or machines that ride on floor-mounted guide rails and power-driven wheels.

Awareness Barrier

Physical and/or visual means that warns a person of an approaching or present hazard.

Awareness Signal

A device that warns a person of an approaching or present hazard by means of audible sound or visible light.

Axis

The line about which a rotating body (such as a tool) turns.

Barrier

A physical means of separating persons from the restricted envelope (space).

Control Device

Any piece of control hardware providing a means for human intervention in the control of a robot or robot system, such as an emergency-stop button, a start button, or a selector switch.

Control Program

The inherent set of control instructions that defines the capabilities, actions and responses of the robot system. This program is usually not intended to be modified by the user.

Coordinated Straight Line Motion

Control wherein the axes of the robot arrive at their respective end points simultaneously, giving a smooth appearance to the motion. Control wherein the motions of the axes are such that the Tool Center Point (TCP) moves along a prespecified type of path (line, circle, etc.)

Device

Any piece of control hardware such as an emergency-stop button, selector switch, control pendant, relay, solenoid valve, sensor, etc.

Drive Power

The energy source or sources for the robot actuators.

Emergency Stop

The operation of a circuit using hardware-based components that overrides all other robot controls, removes drive power from the robot actuators, and causes all moving parts to stop.

Enabling Device

A manually operated device that permits motion when continuously activated. Releasing the device stops robot motion and motion of associated equipment that may present a hazard.

End-effector

An accessory device or tool specifically designed for attachment to the robot wrist or tool mounting plate to enable the robot to perform its intended task. (Examples may include gripper, spot-weld gun, arc-weld gun, spray- paint gun, or any other application tools.)

Energy Source

Any electrical, mechanical, hydraulic, pneumatic, chemical, thermal, or other source.

Envelope (Space), Maximum

The volume of space encompassing the maximum designed movements of all robot parts including the end-effector, workpiece, and attachments.

Restricted Envelope (Space)

That portion of the maximum envelope to which a robot is restricted by limiting devices. The maximum distance that the robot can travel after the limiting device is actuated defines the boundaries of the restricted envelope (space) of the robot.

Operating Envelope (Space)

That portion of the restricted envelope (space) that is actually used by the robot while performing its programmed motions.

Hazard

A situation that is likely to cause physical harm.

Hazardous Motion

Any motion that is likely to cause personal physical harm.

Industrial Equipment

Physical apparatus used to perform industrial tasks, such as welders, conveyors, machine tools, fork trucks, turn tables, positioning tables, or robots.

Industrial Robot

A reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.

Industrial Robot System

A system that includes industrial robots, the end-effectors, and the devices and sensors required for the robots to be taught or programmed, or for the robots to perform the intended automatic operations, as well as the communication interfaces required for interlocking, sequencing, or monitoring the robots.

Interlock

An arrangement whereby the operation of one control or mechanism brings about or prevents the operation of another.

Joint Motion

A method for coordinating the movement of the joints such that all joints arrive at the desired location simultaneously.

Limiting Device

A device that restricts the maximum envelope (space) by stopping or causing to stop all robot motion and is independent of the control program and the application programs.

Maintenance

The act of keeping the robots and robot systems in their proper operating condition.

Mobile Robot

A self-propelled and self-contained robot that is capable of moving over a mechanically unconstrained course.

Muting

The deactivation of a presence-sensing safeguarding device during a portion of the robot cycle.

Numerically controlled machine tools

Are operated by a series of coded instructions comprised of numbers, letters of the alphabet, and other symbols. These are translated into pulses of electrical current or other output signals that activate motors and other devices to run the machine.

Operator

The person designated to start, monitor, and stop the intended productive operation of a robot or robot system. An operator may also interface with a robot for productive purposes.

Pendant

Any portable control device, including teach pendants, that permits an operator to control the robot from within the restricted envelope (space) of the robot.

Presence-Sensing Safeguarding Device

A device designed, constructed, and installed to create a sensing field or area to detect an intrusion into the field or area by personnel, robots, or other objects.

Program

1. (noun) A sequence of instructions to be executed by the computer or robot controller to control a robot or robot system.
2. (verb) to furnish (a computer) with a code of instruction.
3. (verb) to teach a robot system a specific set of movements and instructions to accomplish a task.

Prosthetic robots

are programmable manipulators or devices for missing human limbs.

Rebuild

To restore the robot to the original specifications of the manufacturer, to the extent possible.

Remanufacture

To upgrade or modify robots to the revised specifications of the manufacturer and applicable industry standards.

Repair

To restore robots and robot systems to operating condition after damage, malfunction, or wear.

Robot Manufacturer

A company or business involved in either the design, fabrication, or sale of robots, robot tooling, robotic peripheral equipment or controls, and associated process ancillary equipment.

Robot System Integrator

A company or business who either directly or through a subcontractor will assume responsibility for the design, fabrication, and integration of the required robot, robotic peripheral equipment, and other required ancillary equipment for a particular robotic application.

Safeguard

A barrier guard, device, or safety procedure designed for the protection of personnel.

Safety Procedure

An instruction designed for the protection of personnel.

Sensor

A device that responds to physical stimuli (such as heat, light, sound, pressure, magnetism, motion, etc.) and transmits the resulting signal or data for providing a measurement, operating a control, or both.

Service

To adjust, repair, maintain, and make fit for use.

Single Point of Control

The ability to operate the robot such that initiation or robot motion from one source of control is possible only from that source and cannot be overridden from another source.

Slow Speed Control

A mode of robot motion control where the velocity of the robot is limited to allow persons sufficient time either to withdraw the hazardous motion or stop the robot.

Start-up

Routine application of drive power to the robot or robot system.

Start-up, Initial

Initial drive power application to the robot or robot system after one of the following events:

- Manufacture or modification;
- Installation or reinstallation;
- Programming or program editing; and
- Maintenance or repair.

Teach

The generation and storage of a series of positional data points effected by moving the robot arm through a path of intended motions.

Teach Mode

The control state that allows the generation and storage of positional data points effected by moving the robot arm through a path of intended motions.

Teacher

A person who provides the robot with a specific set of instructions to perform a task.

Teleoperators

Are robotic devices comprised of sensors and actuators for mobility and/or manipulation and are controlled remotely by a human operator.

Tool Center Point (TCP)

The origin of the tool coordinate system.

Undersea and space robots

Include in addition to the manipulator or tool that actually accomplishes a task, the vehicles or platforms that transport the tools to the site. These vehicles are called remotely operated vehicles (ROV's) or autonomous undersea vehicles (AUV's); the feature that distinguishes them is, respectively, the presence or absence of an electronics tether that connects the vehicle and surface control station.

User

A company, business, or person who uses robots and who contracts, hires, or is responsible for the personnel associated with robot operation.